AL/CF-TR-1994-0051

GENERATOR OF BODY (GEBOD) MANUAL

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MARCH 1994

DTIC QUALITY INSPECTED 3

MANUAL FOR THE PERIOD APRIL 1991 TO MARCH 1994

19950111 088

AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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AL/CF-TR-1994-0051

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Service (NTIS). At NTIS, it will be available to the general
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This technical report has been reviewed and is approved for
publication.

FOR THE DIRECTOR

Thomas J. Moore

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 1994	3. REPORT TYPE AND DATES COVERED Final Report Apr 91 to Mar 94

4. TITLE AND SUBTITLE
Generator of Body Data (GEBOD) Manual

5. FUNDING NUMBERS
PE 62202F
PR 7231
TA 23
WU 01

6. AUTHOR(S)
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Louise Obergefell
Annette Rizer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Systems Research Laboratories, Inc.
2800 Indian Ripple Rd.
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate
Biodynamics and Biocommunications Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7901

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/CF-TR-1994-0051

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Generator of Body Data (GEBOD) program is an interactive computer program that produces the human and dummy body description data used by the Articulated Total Body (ATB) model. GEBOD computes the body segments' geometric and mass properties, and the joints' locations and mechanical properties. These data may be computed for children, adult human males, adult human females, or anthropomorphic dummies. This report is a comprehensive manual that covers the applicable material from earlier reports and the most recent upgrades to the GEBOD program, including improved height calculations. The user's guide section of the report describes how to run the program and what options are available. A more detailed description of how the data is generated and on what studies the calculations are based is included in the program description section. Also included are a brief history of GEBOD's development, a detailed description of GEBOD program subroutines, and example output files.

14. SUBJECT TERMS
Anthropometry, Data Base, Biodynamic Modeling

15. NUMBER OF PAGES
70

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

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PREFACE

This manual documents the Generator of Body Data (GEBOD) program version IV. To provide a complete manual, portions of Baughman's "Development of an Interactive Computer Program to Produce Body Description Data," AFAMRL-TR-83-058, and Gross' "The GEBODIII Program User's Guide and Description," AL-TR-1991-0102, have been incorporated into this report.

The human and manikin body data base improvements and the GEBODIV program enhancements documented in this manual have been supported by both the Armstrong Laboratory and the National Highway Traffic Safety Administration.

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INTRODUCTION

General Description

The use of the Articulated Total Body (ATB) Model (Ref 1, 2) for occupant simulation requires extensive data to describe human and dummy geometric and inertial properties. The modeling approach used in the ATB model considers the body as being divided into individual rigid segments, typically 15 or 17 segments. The segments are joined at locations representing the physical joints of the human body and have the mass of the body between body joints. To satisfy this requirement, GEBOD (GEnerator of BODy Data) (Ref 3 and Ref 4) was developed to generate human and dummy data sets. The data sets include the body segments' geometric and mass properties, and the joints' locations and mechanical properties. Regression equations from anthropometric surveys and stereophotometric data (Ref 5 to 9) are used in computing these data sets. The program is written in FORTRAN 77 and has a simple user interface. It creates an occupant description data file formatted to be directly inserted into an ATB occupant simulation input file.

History of Development

In 1973, Calspan Corporation developed the GOOD (Generator of Occupant Data) program (Ref 10) in order to automate the production of input data sets for the Crash Victim Simulator (CVS) program (Ref 11) which is used for simulation of occupant dynamics in three dimensions during automobile crashes. The ATB model is a later version of CVS incorporating modifications such as aerodynamic forces and a harness belt capability for simulation of aircraft ejections and complex vehicle crashes. Correspondingly, GEBOD is an extensive modification of GOOD, developed to generate ATB model input data. GEBOD used a set of 32 body dimensions to compute the joint center locations and the

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segment sizes, masses and principal moments of inertia. Version III of GEBOD (Ref 4) has additional options for 17 segments (separate lower arm and hand segments) and dummy data sets. GEBODIII also uses the stereophotometric survey data (Ref 8 and 9) in the calculation of the joint center locations, and segment masses and inertial properties, improving the accuracy of these data. The joint and ellipsoid location calculations are corrected to provide accurate sitting and standing heights in version IV. GEBODIV is the latest version of GEBOD and this report is the revised version of "The GEBODIII Program User's Guide and Description".

Modifications in GEBODIV

For the adult humans, there are four groups of regression equations, corresponding to the computation of body measurements, joint locations, segment volumes for mass calculation and segment principal moments of inertia. Each group of regression equations were computed from body measurement survey data or stereophotometric data. Each group of regression equations is independent of the other groups. For example, there is no relationship between the arm length and the elbow location generated by the regression equations. This can result in inconsistencies between the joint locations and the body measurements in GEBODIII. For example, the standing and seated heights calculated from the sum of joints' coordinates are different from those obtained directly from standing and seated height regression equations of body measurements. GEBODIV has a modified algorithm for calculating the joint locations, ellipsoid semiaxes, and ellipsoid locations which corrects these inconsistencies

In the ATB model, each segment is depicted with a contact ellipsoid. The ellipsoid's size and location are related to the segment's dimensions and joint locations. GEBODIII located the

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ellipsoid center in each segment's local reference system by a
method of visual alignment. This resulted in some errors,
especially for extremely short or tall subjects.

GEBODIV addresses this problem by calculating the ellipsoid
center coordinates based on the corresponding joint locations and
the segment's dimensions.

GEBOD is an interactive, menu-driven program. Upon starting, the
user is asked for a subject description and an output filename.
The description can be up to 60 characters long. The program
automatically assigns the appropriate extensions to the output
filename. Next the user is asked to select the subject type:

1) Child (2-19 years)
2) Adult Human Female
3) Adult Human Male
4) User-Supplied Body Dimensions
5) Seated Hybrid III Dummy (50th %tile)
6) Standing Hybrid III Dummy (50th %tile)
7) Hybrid II Dummy (50th %tile)

Based on this selection, the user is asked the additional
questions described in the following sections.

Child

The child data sets are based on the 1977 Snyder, et. al. study
(Ref 6). The joint torque characteristics are those used by
Kaleps and Marcus (Ref 12).

When the child option is selected, the user is asked if the data
set is to be generated based on the child's age, weight, height,
or all three. Based on the user's selection, the user is
prompted for the child's age, weight, and/or height. The user
selects the units of measurement for each of these values, and
the program provides the allowable ranges for each input.

Adult Human Female

The female data sets are based on the 1983 female stereophotometric study of Young, et. al. (Ref 8) and the 1972 Air Force female anthropometric survey from Clauser, et. al. (Ref 5). The joint torque characteristics were developed using Engin's data (Ref 13).

When the female option is selected, the user is asked if the data set is to be generated based on the female's weight, height, or both. Based on the user's selection, the user is prompted for the female's weight and/or height. The user can opt to input these values in English or metric units or to specify their percentile. The program provides the allowable ranges for each input. The user can then select how the forearm and hand are to be configured. They can be combined as one segment for the standard 15 segment body or separated as two independent segments for a 17 segment body.

Adult Human Male

The male data sets are based on the 1980 male stereophotometric study of McConville, et. al. (Ref 9) and the 1967-68 Air Force flying personnel anthropometric study of Grunhofer (Ref 7). The joint torque characteristics are the same as for the females.

When the male option is selected, the user is given the same input choices as for the female option described in the previous section.

User-Supplied Body Dimensions

This option allows the user to input a more specific body configuration, rather than just height and weight, as in the two previous options. When this option is used, the body data is

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generated based on the input data rather than the anthropometric surveys and the stereophotometric studies. The joint torque characteristics are the same as for the two previous options.

When the user-supplied full body dimensions option is selected, the user is asked for the filename with extension containing the body dimensions and whether the dimensions are in English (inches and pounds) or metric (meters and Newtons) units.

The input file must contain the 32 body dimensions listed in the order of Table 1. The dimensions should be listed in four rows of eight with field lengths of ten. Descriptions of these

Table 1 Body Dimensions

#	DIMENSION	#	DIMENSION
0	Weight	16	Hip Breadth, Standing
1	Standing Height	17	Shoulder to Elbow Length
2	Shoulder Height	18	Forearm-Hand Length
3	Armpit Height	19	Biceps Circumference
4	Waist Height	20	Elbow Circumference
5	Seated Height	21	Forearm Circumference
6	Head Length	22	Waist Circumference
7	Head Breadth	23	Knee Height, Seated
8	Head to Chin Height	24	Thigh Circumference
9	Neck Circumference	25	Upper Leg Circumference
10	Shoulder Breadth	26	Knee Circumference
11	Chest Depth	27	Calf Circumference
12	Chest Breadth	28	Ankle Circumference
13	Waist Depth	29	Ankle Height, Outside
14	Waist Breadth	30	Foot Breadth
15	Buttock Depth	31	Foot Length

dimensions are included in Appendix A. The program does not check the body dimensions for consistency. Therefore the user should carefully check the data set generated using this option for unrealistic dimensions.

Hybrid III Dummies

The seated Hybrid III dummy data set is for a 50th percentile dummy with a seated pelvis and the standing Hybrid III dummy data set is for a 50th percentile dummy with a standing pelvis. Kaleps, et. al. (Ref 14) describe the development of these data sets.

Hybrid II Dummy

The Hybrid II dummy data set is the original Part 572 50th percentile dummy data set developed for the Crash Victim Simulator (VCS) program by Fleck, et. al. (Ref 15).

Files Generated

The user is asked if the output should be in English or metric units and if a file formatted for the Articulated Total Body (ATB) model input is wanted. GEBOD always generates a file (extension .TAB) that contains labeled tables of the calculated data set and a list of the body dimensions for the human data sets. An ATB input file (extension .AIN) is also generated if requested. Example output files are listed in Appendix D.

The user will be returned to the beginning of the program if they respond yes when asked if additional data sets are desired. Otherwise the program is exited.

Depending on the chosen subject type, one of four methods is used
to generate the required body data. The data for the Hybrid II
and III dummies are contained in the GEBOD.DAT file and GEBOD
simply reads these data and transforms them into the appropriate
units. The procedures used in generating the adult male and
female, child, and user-supplied dimensions option data sets are
illustrated in Figures 1, 2, and 3 respectively. The rectangular
boxes symbolize sets of data, and the ovals symbolize processes
or equations that operate on the data. These data and processes
are described in the following sections.
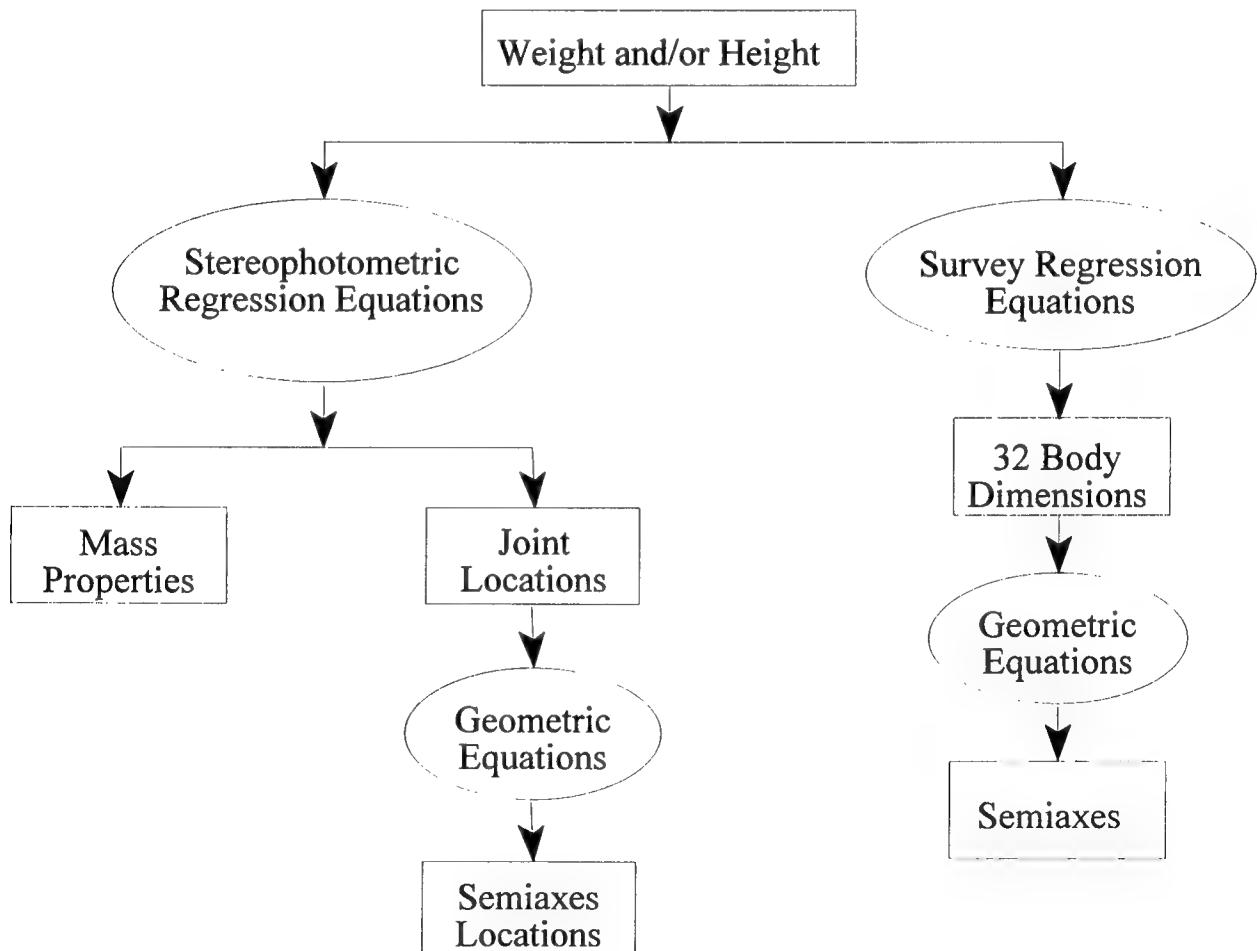
Figure 1   Procedures Used in Generating Adult Male and Female
                 Subjects
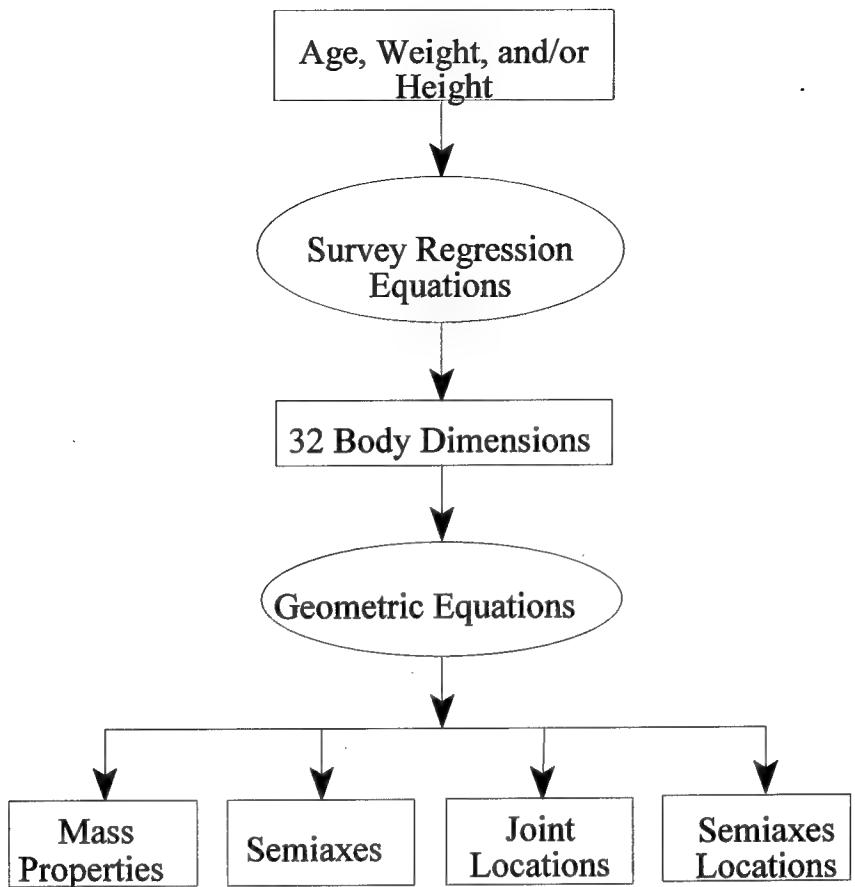
Figure 2   Procedures Used in Generating Child Subjects
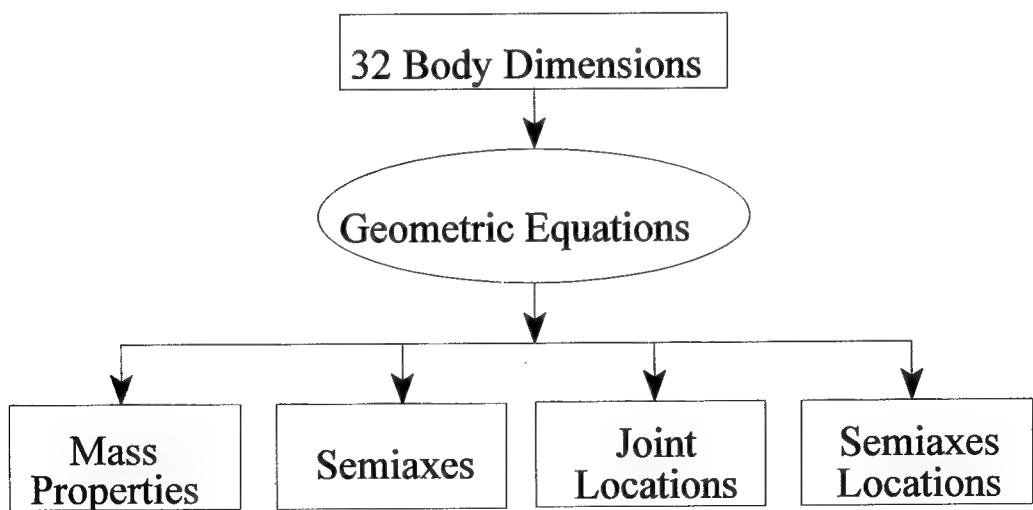
Figure 3   Procedures Used in Generating Subjects with User-
                  Supplied Dimensions

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Regression Equations

Regression equations are used in the child, and adult human male and female options. It is a method widely used in anthropometry for predicting unknown body dimensions from known body dimensions, using a database of measurements taken from several human subjects. In GEBOD, there are four groups of regression equations which are used to determine the body dimension set, joint location coordinates, segment volumes, and principal moments of inertia. Each group has two sets of equations for female and male subjects respectively, except for the body dimension set which has a third set for children. Each regression equation is a first order linear equation with either standing height or body weight, or both of them as the independent variables. For the child regression equations, an additional independent variable of age is used. For example, the regression equation to predict adult female shoulder height can be found as follows:

Shoulder Height = 0.07182(Body Weight) + 42.77

Shoulder Height = 0.8751(Standing Height) - 3.936

Shoulder Height = 0.00755(Body Weight) + 0.8469(Standing Height)
         - 3.096

where the body weight and standing height are the input variables which the user supplied. Depending on the user input, one of the above three equations is used to obtain the shoulder height. The R^2 values for the above three equations are 0.3094, 0.9194 and 0.9218, respectively. As expected, the equation using both weight and height has the best predictive ability.

Reference Axis Systems

All data output by GEBOD are described with respect to the segment local reference axis systems. Each segment's local axis system is defined such that its origin is at the segment center

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of mass. When the body is in a standing position with the toes
pointing down for humans or pointing forward for dummies, the
local axis systems' positive Z-axes point down, positive X-axes
point forward, and positive Y-axes point to the right of the
body.

Body Dimensions

For the child and adult human options, the body dimensions in
Table 1 are generated from regression equations based on input
height, weight, and/or age. These regression equations are
stored in GEBOD and were computed from data given by Ref 5, 6 and
7. As the name implies, the user supplied body dimensions option
obtains the body dimensions from an input file supplied by the
user.

Body Geometry

The structure and appearance of the human model as depicted by
the ATB model is determined from contact ellipsoid semiaxes and
joint locations. A contact ellipsoid is associated with each
body segment, giving the segment shape and providing an
interaction surface between the segment and its environment. The
joints connect segments and serve as pivot points about which
rotational motion is allowed. A joint is located relative to the
two segments it connects. For example, the elbow joint is
located by two sets of three-dimensional coordinates: one set
relative to the local reference system of the upper arm; the
other relative to the local reference system of the forearm.

Child and User-Supplied Options

GEBOD computes joint locations using the expressions listed in
Table 2, where D_i is the ith body dimension listed in Table 1.
These expressions were developed using the center of each

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JOINT	RELATIVE TO	LOCATION		
		X	Y	Z
Abdomen-pelvis	pelvis	0.0	0.0	$(D_1 - D_5 - D_4 + 0.1(D_2 - D_4))/2$
	abdomen	0.0	0.0	$(D_2 - D_4)/10$
Thorax-abdomen	abdomen	0.0	0.0	$-(D_2 - D_4)/10$
	thorax	0.0	0.0	$9(D_2 - D_4)/20$
Neck-thorax	thorax	0.0	0.0	$-9(D_2 - D_4)/20$
	neck	0.0	0.0	$(D_1 - D_8 - D_2 - D_9/(2\pi))/2$
Head-neck	neck	0.0	0.0	$-(D_1 - D_8 - D_2 - D_9/(2\pi))/2$
	head	0.0	0.0	$(D_8 + D_9/(2\pi))/2$
Right hip	pelvis	0.0	$(D_{16} - D_{24}/\pi)/2$	$(D_4 - (D_2 - D_4)/10 - D_1 + D_5 - D_{24}/\pi)/2$
	right thigh	0.0	0.0	$-(D_1 - D_5 - D_{23} + D_{26}/\pi)/2$
Right knee	right thigh	0.0	0.0	$(D_1 - D_5 - D_{23} + D_{24}/\pi)/2$
	right calf	0.0	0.0	$-(D_{23} - D_{29} + D_{28}/(2\pi) - D_{26}/\pi)/2$
Right ankle	right calf	0.0	0.0	$(D_{23} - D_{29} - D_{28}/(2\pi))/2$
	right foot	$D_{29}/2$	0.0	$-(D_{31} - D_{28}/\pi)/2$
Left hip	pelvis	0.0	$-(D_{16} - D_{24}/\pi)/2$	$(D_4 - (D_2 - D_4)/10 - D_1 + D_5 - D_{24}/\pi)/2$
	left thigh	0.0	0.0	$-(D_1 - D_5 - D_{23} + D_{26}/\pi)/2$
Left knee	left thigh	0.0	0.0	$(D_1 - D_5 - D_{23} + D_{24}/\pi)/2$
	left calf	0.0	0.0	$-(D_{23} - D_{29} + D_{28}/(2\pi) - D_{26}/\pi)/2$
Left ankle	left calf	0.0	0.0	$(D_{23} - D_{29} - D_{28}/(2\pi))/2$
	left foot	$D_{29}/2$	0.0	$-(D_{31} - D_{28}/\pi)/2$
Right shoulder	thorax	0.0	$(D_{10} - D_{19}/\pi)/2$	$-(D_2 - D_3 - D_{19}/(2\pi))$
	right upper arm	0.0	0.0	$-(D_{17} - D_{19}/\pi)/2$
Right elbow	right upper arm	0.0	0.0	$(D_{17} - D_{20}/\pi)/2$
	right forearm	0.0	0.0	$-(D_{18} - D_{20}/\pi)/2$
Left shoulder	thorax	0.0	$-(D_{10} - D_{19}/\pi)/2$	$-(D_2 - D_3 - D_{19}/(2\pi))$
	left upper arm	0.0	0.0	$-(D_{17} - D_{19}/\pi)/2$
Left elbow	left upper arm	0.0	0.0	$(D_{17} - D_{20}/\pi)/2$
	left forearm	0.0	0.0	$-(D_{18} - D_{20}/\pi)/2$

segment's contact ellipsoid as an approximation for the center of gravity. Joint coordinates computed using these expressions, then, are not actually relative to segment local reference system, but to a parallel set of axes located at the ellipsoid center. Once GEBOD has computed the location of the segment center of gravity, the appropriate translation is applied to convert to the local reference system.

Relative to the segment ellipsoid axis system described, it has been possible to make certain assumptions, simplifying the development of the expressions for joint locations listed in Table 2. First, the x coordinate of all joints relative to appropriate ellipsoid reference system, with the exception of the ankles relative to the feet, are zero. Secondly, it is assumed that the only joints with non-zero Y ellipsoid reference coordinates are the shoulders relative to the thorax and the hips relative to the pelvis.

Similarly, expressions for contact ellipsoid semiaxes are listed in Table 3. Specific methods used to obtain these expressions are described in the following.

Table 3 Contact Ellipsoid Semiaxes (All Options)

SEGMENT	X SEMIAXIS	Y SEMIAXIS	Z SEMIAXIS
Pelvis	$D_{15}/2$	$D_{16}/2$	$(D_4+D_5-D_1-0.1(D_2-D_4))/2$
Abdomen	$D_{13}/2$	$D_{14}/2$	$(D_2-D_4)/10+D_9/\pi$
Thorax	$D_{11}/2$	$D_{12}/2$	$0.45(D_2-D_4)$
Neck	$D_9/(2\pi)$	$D_9/(2\pi)$	$(D_1-D_8-D_2+D_9/(2\pi))/2$
Head	$D_6/2$	$D_7/2$	$(D_8+D_9/(2\pi))/2$
Right and Left Thigh	$(D_{24}+D_{25})/(4\pi)$	$(D_{24}+D_{25})/(4\pi)$	$(D_1-D_5-D_{23}+(D_{24}+D_{26})/\pi)/2$
Right and Left Calf	$D_{27}/(2\pi)$	$D_{27}/(2\pi)$	$(D_{23}-D_{29}+D_{28}/(2\pi))/2$
Right and Left Foot	$D_{29}/2$	$D_{30}/2$	$D_{31}/2$
Right and Left Upper Arm	$D_{19}/(2\pi)$	$D_{19}/(2\pi)$	$D_{17}/2$
Right and Left Forearm	$D_{21}/(2\pi)$	$D_{21}/(2\pi)$	$D_{18}/2$

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Torso

The torso is divided by defining the mid torso or abdomen as extending from the tenth rib landmark to the iliocristale landmark, with the thorax being all of the torso above the tenth rib, and the pelvis being all of the torso below the iliocristale landmark.

Since none of the 32 body measurements being used give tenth rib height, the landmarks located in the two stereophotometric studies (Ref 9 and 16) were examined. It was found that the ratio of thorax height (vertical distance between suprasternale and tenth rib midspine) to abdomen height (vertical distance between tenth rib midspine and right iliocristale) averages about 4:1. Using this result the distance between the thorax-abdomen joint and the abdomen-pelvis joint was set to be one-fifth of the difference between the shoulder and waist heights, $(D_2 - D_4)/5$.

When developing the expressions for the torso joint locations, these locations were first laid out in a global setting, with the axis origin on the floor (that is vertical distance from the floor). The top of the thorax was determined by shoulder height (D_2), and the distance from the floor to the bottom of the pelvis was taken as the difference between the standing height and seated height $(D_1 - D_5)$. The center of the abdomen was then located by waist height (D_4). The abdomen-pelvis joint and the thorax-abdomen joint were located so that the center of the abdomen is mid-way between the two joints (recall that the distance between these two joints is $(D_2 - D_4)/5$). The center of the thorax was then placed mid-way between the thorax abdomen joint and top of the torso, and the center of the pelvis was placed mid-way between the bottom of the pelvis and the abdomen-pelvis joint. From these global locations, the expressions for local reference system coordinates of torso joints were determined.

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The Z semiaxis of the pelvis contact ellipsoid is set equal to
the distance from the center of the pelvis to the abdomen-pelvis
joint. This causes the pelvis contact ellipsoid to cover the
pelvis vertically from the abdomen-pelvis joint to the bottom of
the pelvis (D_1 - D_5), since the pelvis center is mid-way between
these points. Similarly, the Z semiaxis of the thorax contact
ellipsoid is set equal to the distance from center of the thorax
to the thorax-abdomen joint, which results in the contact
ellipsoid covering the thorax from the top of the thorax (D_2) to
the thorax-abdomen joint. For the resulting model to have a
proper appearance, there must be some overlap between adjacent
contact ellipsoids. Since this overlap is primarily for
appearance, the extent of overlap utilized is the neck radius
($D_{29}/2\pi$). This is the amount that the abdomen contact ellipsoid
overlaps both the thorax contact ellipsoid and the pelvis contact
ellipsoid.

Head and Neck

As in the torso, the segment centers and joint locations
involving the head and neck were first laid out globally. First,
the top of the head was placed at the standing height (D_1), and
the neck-thorax joint was placed at the shoulder height (D_2). In
order to provide overlap, the Z semiaxis of the head is set to
one half of the quantity, head height plus neck radius; that is
(D_8 + $D_9/(2\pi)$)/2.

The center of the head is then determined by the standing height
minus the Z semiaxis of the head, and the head-neck joint is
located by the standing height minus twice the Z semiaxis of the
head. The center of the neck is located mid-way between the
head-neck joint and the neck-thorax joint. The top of the neck
contact ellipsoid is desired to be at the standing height minus
head height (D_1 - D_8). Therefore the Z semiaxis of the neck

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contact ellipsoid is set to the distance between this location
and the center of the neck.

Feet

As with the other limb segments, the Z reference axis of each
foot runs the length of the segment (from heel to toe). For
simplicity in developing expressions for the joint locations, the
foot is viewed in a normal position for a standing model. This
rotates the foot reference system 90 degrees from the reference
systems of other segments, i.e. Z forward, X upward, and Y to the
right. The location of the ankle joint in the vertical (X)
direction is the ankle height D_{29} from the bottom of the foot, or
one half this distance from the center of the foot. In the Z-
horizontal direction, the ankle joint is located at an ankle
radius $(D_{29}/2\pi)$ in front of the back of the foot, and the center
of the foot is located at one-half the foot length $(D_{31}/2)$ from
the back of the foot in this direction.

Limb Segments

A concept of joint spheres is used in developing expressions for
the limb semiaxes and joint locations. The usage of this concept
is illustrated in Figure 4.

Adult Human Options

For the human adult options, the approach to compute joint
locations and mass properties uses the stereophotometric data.
Using stereophotometrics, the three-dimensional coordinates of a
large number of points on living subjects can be collected and
used to "recreate" the actual body surface and generate accurate
geometric and mass distribution data. From the stereophotometric
studies (Ref 8 and 9), several groups of regression equations are
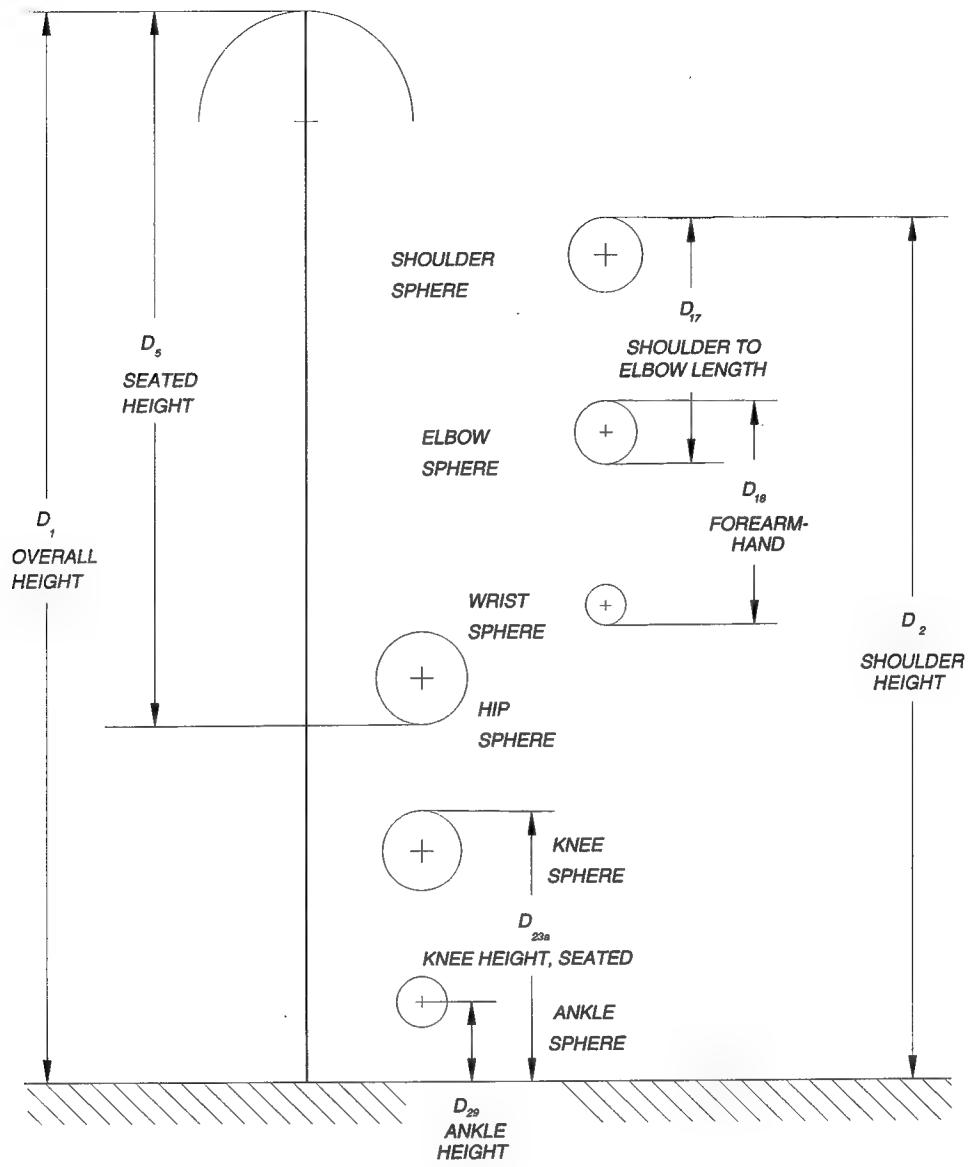
Radii of these spheres are as follows:
Shoulder sphere: $D_{19}/(2\pi)$
Elbow sphere: $D_{20}/(2\pi)$
Wrist sphere: $D_{22}/(2\pi)$
Hip sphere: $D_{24}/(2\pi)$
Knee sphere: $D_{26}/(2\pi)$
Ankle sphere $D_{28}/(2\pi)$

Figure 4   Joint Sphere Concept Used to Determine Joint
            Locations Relative to Limb Segments

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generated for both male and female subjects to calculate the geometric and mass parameters.

The stereophotometric data was collected in a global axis system defined with the body in the standard anatomical position with the origin on the floor centrally located between the subject's feet and directly underneath the body. The axes are defined so that the positive X axis points forward, positive Y axis points to the left of the body, and positive Z axis points upward from the origin. The hands of the female subjects were positioned with the palms facing anteriorly; the hands of the male subjects were positioned with the palms facing posteriorly.

In the stereophotometric surveys, a series of landmarks on the surface of each subject were targeted and the three dimensional coordinates of the landmarks were measured during the stereophotometric assessment (Ref 8 and 9). Table 4 contains a list of these landmarks. L_i stands for the ith landmark.

In segmenting the data, McConville (Ref 9) and Young (Ref 8) defined the standard anatomical axis systems for each segment based on these landmarks. In general, the anatomical axis systems are defined so that the positive X-axes point forward, positive Y-axes point to the body's left, and positive Z-axes point distal to proximal. Complete definitions of the anatomical axis systems are given in McConville, et al. (Ref 9) for males and Young, et al. (Ref 8) for females.

Based on the above definitions, the transformation from the segment anatomical axis system to the local axis system consists of a translation to the segment center of mass and a 180 degree rotation about the anatomical X-axis for all the segments except the neck and pelvis. The landmarks used to define the anatomical axis systems for these two segments result in X-axes that are not horizontal in the standing position. Therefore, the

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Table 4   Stereophotometric Landmarks

Landmark	Landmark Name
L_1	Left Tragion
L_2	Right Tragion
L_3	Cervicale
L_2	Tenth Rib Midspine
L_4	Posterior Superior Iliac Midspine
L_5	Right Acromion
L_6	Right Medial Humeral Epicondyle
L_7	Right Lateral Humeral Epicondyle
L_8	Right Radial Styloid
L_9	Right Ulnar Styloid
L_{10}	Left Acromion
L_{11}	Left Medial Humeral Epicondyle
L_{12}	Left Lateral Humeral Epicondyle
L_{13}	Left Radial Styloid
L_{14}	Left Ulnar Styloid
L_{15}	Right Trochanterion
L_{16}	Right Anterior Superior Iliac Spine
L_{17}	Symphysion
L_{18}	Right Lateral Femoral Epicondyle
L_{19}	Right Medial Femoral Epicondyle
L_{20}	Right Medial Malleolus
L_{21}	Right Lateral Malleolus
L_{22}	Left Trochanterion
L_{23}	Left Anterior Superior Iliac Spine
L_{24}	Left Lateral Femoral Epicondyle
L_{25}	Left Medial Femoral Epicondyle
L_{27}	Left Medial Malleolus
L_{28}	Left Lateral Malleolus

transformation from the segment anatomical axis system to the local axis system for these two segments includes a rotation about the Y-axis after the X-axis rotation. For the neck, this Y-axis rotation is +30 degrees and for the pelvis, -12 degrees. The transformation cosine matrix from the neck anatomical axis system to the neck local axis system is:

$$\begin{bmatrix} \cos(30°) & 0 & \sin(30°) \\ 0 & -1 & 0 \\ \sin(30°) & 0 & -\cos(30°) \end{bmatrix}$$

The transformation cosine matrix from the pelvis anatomical axis system to the pelvis local axis system is:

$$\begin{bmatrix} \cos(12°) & 0 & -\sin(12°) \\ 0 & -1 & 0 \\ -\sin(12°) & 0 & -\cos(12°) \end{bmatrix}$$

The transformation cosine matrix from the anatomical axis system to the local axis system for all other segments is:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

In the stereophotometric data for the adult human female forearms, the anatomical Z-axis is represented as a vector from the ulnar styloid landmark to the radiale landmark. This vector crosses the forearm diagonally from lateral to medial which did not conform to the desired vertical alignment of the segment axes. Therefore, the anatomical axes for the female were redefined as follows:

    RIGHT FOREARM
        Z axis - vector from radial styloid to radiale
        Y axis - normal from Z axis to ulnar styloid
        X axis - Y x Z
        Origin - at radiale

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LEFT FOREARM
  Z axis - vector from radial styloid to radiale
  Y axis - normal from ulnar styloid to Z axis
  X axis - $\underline{Y} \times \underline{Z}$
  Origin - at radiale

The local reference axes for the right and left forearm segments were also obtained by rotating the above anatomical axes 180 degrees about the X axis and translating the origin to the center of mass.

Joint Center Locations

Based on the landmark locations, the three-dimensional joint center locations were calculated in the global axis system for each male and female stereophotometric subject. Table 5 contains a list of the joint center location expressions where L_{ix}, L_{iy}, and L_{iz} (i = 1..28) stand for the X, Y, Z coordinates of the ith landmark. The expression used to locate the hip joint center is from Andriacchi and Strickland (Ref 17). All other expressions were obtained by experimentation. These global joint center locations were transformed to the local reference axis systems. The resulting joint center locations were then used to calculate regression equations to estimate joint center locations in the local reference axis system for adult human female and male subject type options.

Because these landmarks were measured separately from each other, no relationships exist between the calculated joint locations. Therefore, when the vertical distances between the joints are added together, they do not correspond exactly with the input standing and seated heights. GEBODIV corrects this inconsistency by introducing the standing height, seated height and arm length as a set of constraints on the joint center

JOINT	LOCATION		
	X	Y	Z
Head-Neck	$(L_{1X}+L_{2X})/2$	$(L_{1Y}+L_{2Y})/2$	$(L_{1Z}+L_{2Z})/2-1.1811$
Neck-Thorax	$L_{3X}+2.0079$	L_{3Y}	$L_{3Z}-0.9843$
Thorax-Abdomen	$L_{4X}+2.0079$	L_{4Y}	L_{4Z}
Abdomen-Pelvis	$L_{5X}+2.0079$	L_{5Y}	L_{5Z}
Right Shoulder	L_{6X}	$L_{6Y}+1.4961$	$L_{6Z}-1.4961$
Right Elbow	$(L_{7X}+L_{8X})/2$	$(L_{7Y}+L_{8Y})/2$	$(L_{7Z}+L_{8Z})/2$
Right Wrist	$(L_{9X}+L_{10X})/2$	$(L_{9Y}+L_{10Y})/2$	$(L_{9Z}+L_{10Z})/2$
Left Shoulder	L_{11X}	$L_{11Y}-1.4961$	$L_{11Z}-1.4961$
Left Elbow	$(L_{12X}+L_{13X})/2$	$(L_{12Y}+L_{13Y})/2$	$(L_{12Z}+L_{13Z})/2$
Right Hip	L_{16X}	$(L_{17Y}+L_{18Y})/2$	$(L_{17Z}+L_{18Z})/2-0.5906$
Right Knee	$(L_{19X}+L_{20X})/2$	$(L_{19Y}+L_{20Y})/2$	$(L_{19Z}+L_{20Z})/2$
Right Ankle	$(L_{21X}+L_{22X})/2$	$(L_{21Y}+L_{22Y})/2$	$(L_{21Z}+L_{22Z})/2$
Left Hip	L_{23X}	$(L_{18Y}+L_{24Y})/2$	$(L_{18Z}+L_{24Z})/2-0.5906$
Left Knee	$(L_{25X}+L_{26X})/2$	$(L_{25Y}+L_{26Y})/2$	$(L_{25Z}+L_{26Z})/2$
Left Ankle	$(L_{27X}+L_{28X})/2$	$(L_{27Y}+L_{28Y})/2$	$(L_{27Z}+L_{28Z})/2$

locations. The coefficients of the joint location regression
equations are adjusted to satisfy these constraints.

In order to satisfy both the standing and seated height
constraints, two new dimensions, H_1 and H_2, are defined as the
distances from the top of the head to the bottom of the hip
sphere and from the hip joint to the standing surface,
respectively. H_1 includes the joints above and including the hip
joint. H_2 covers the remaining joints. Figure 5 illustrates the
partition of the total body dimensions with A,B,... representing
either the joint location z coordinates or ellipsoid semiaxes and
offsets. H_1 is used to satisfy the seated height and H_2 is used
to satisfy the standing height constraints. The modification of
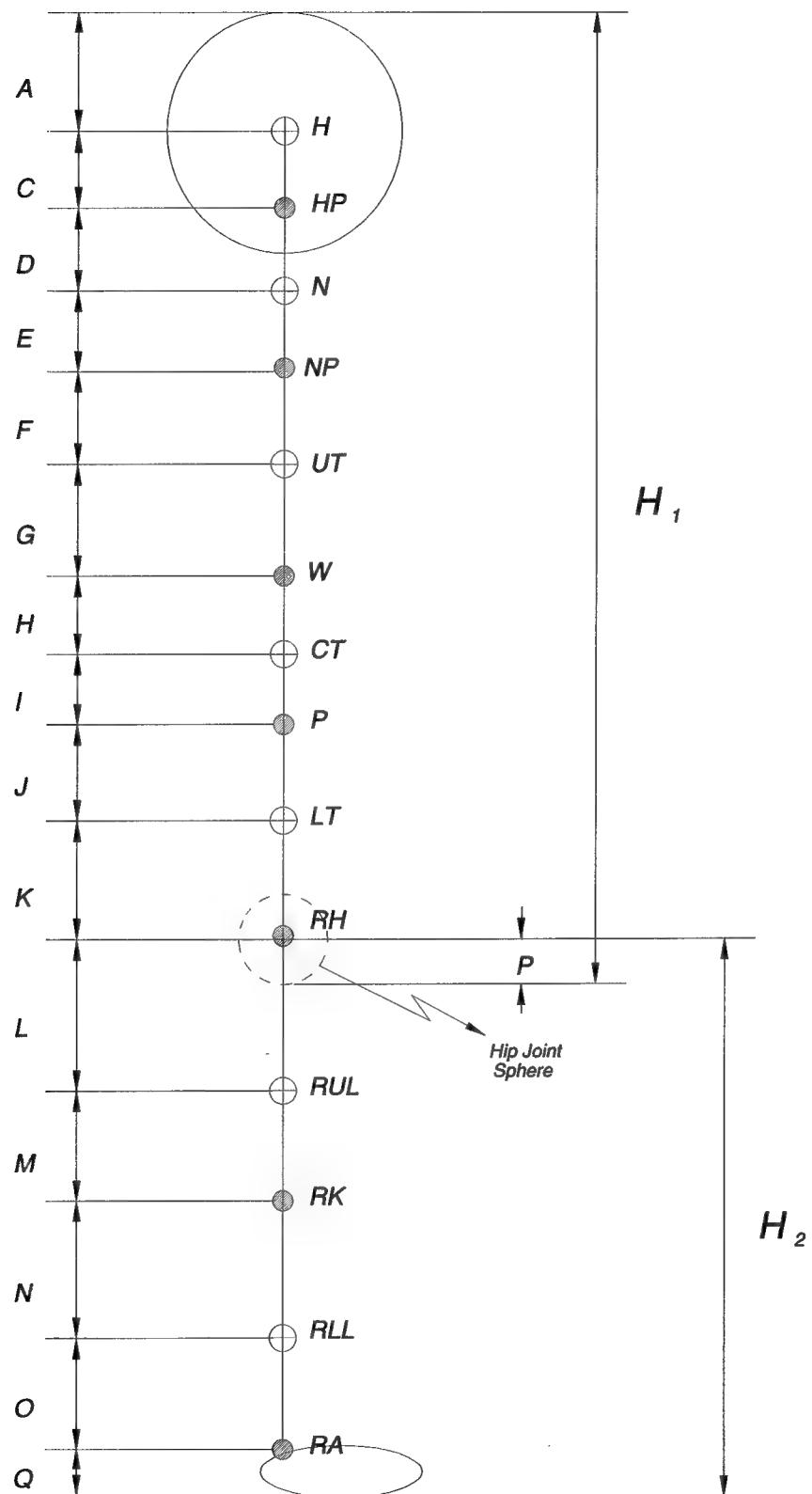
Figure 5 Partition of the Total Body Dimensions

the joint locations is only applied to the vertical dimensions, i.e., the Z coordinates. The X and Y coordinates are not changed.

As stated before, a joint Z coordinate with respect to the corresponding segment's center of mass is given by a joint regression equation. These equations have the same format for all of the joints. That is:

$$Z_i = a_i W + b_i h_t + c_i \qquad\qquad i = C, D, E, \ldots \tag{1}$$

where W is the total body weight and h_t is the standing height. They are input by the user. a_i, b_i, and c_i are the coefficients and i refers to the ith joint. Similarly, each body dimension D_j has the same type of regression equations as follows:

$$D_j = \alpha_j W + \beta_j h_t + \gamma_j \qquad\qquad j = 0, 1, \ldots 31 \tag{2}$$

where α_j, β_j, and γ_j are the coefficients and j refers to the jth body dimension.

The head Z semiaxes is calculated using two head dimensions,

$$A = \frac{D_8}{2} + \frac{D_9}{4\pi} \tag{3}$$

and the hip sphere is:

$$P = \frac{D_{24}}{2\pi} \tag{4}$$

Therefore,

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$$H_1 = \sum_{i=C}^{K} Z_i + A + P \tag{5}$$

Substituting Eqs. (1)-(4) into (5):

$$H_1 = \overline{a}_1 W + \overline{b}_1 h_t + \overline{c}_1 \tag{6}$$

where,

$$\overline{a}_1 = \sum_{i=C}^{K} a_i + \frac{\alpha_8}{2} + \frac{\alpha_9}{4\pi} + \frac{\alpha_{24}}{2\pi}$$

$$\overline{b}_1 = \sum_{i=C}^{K} b_i + \frac{\beta_8}{2} + \frac{\beta_9}{4\pi} + \frac{\beta_{24}}{2\pi} \tag{7}$$

$$\overline{c}_1 = \sum_{i=C}^{K} c_i + \frac{\gamma_8}{2} + \frac{\gamma_9}{4\pi} + \frac{\gamma_{24}}{2\pi}$$

In Eqs. (7), the summation actually is not a simple addition of terms. It includes a transformation from anatomical to local coordinates as explained in the previous section. Using Eq. (6) and seated height D_5 from the 32 body dimension data set,

$$D_5 = \alpha_5 W + \beta_5 h_t + \gamma_5 \tag{8}$$

the seated height constraint can be imposed by introducing a set of coefficient corrections (Δa_1, Δb_1, Δc_1) for the joints above the hip as follows:

$$(\overline{a}_1 + \Delta a_1) W + (\overline{b}_1 + \Delta b_1) h_t + (\overline{c}_1 + \Delta c_1) = \alpha_5 W + \beta_5 h_t + \gamma_5 \tag{9}$$

The set of corrections can be obtained by equating the corresponding coefficients between the two sides:

$$\Delta a_1 = \alpha_5 - \overline{a}_1$$
$$\Delta b_1 = \beta_5 - \overline{b}_1 \tag{10}$$
$$\Delta c_1 = \gamma_5 - \overline{c}_1$$

The standing height constraint can be applied by adjusting the Z coordinate of the joints below hip joint. That is, by calculating H_2 in a similar way as H_1 by using the following constraint equation:

$$D_5 + H_2 - P = h_t, \tag{11}$$

another set of coefficient corrections for the joints below the hip, Δa_2, Δb_2, and Δc_2 are obtained. The same method is used to obtain the correction coefficients based on the arm length. The derived results of $(\Delta a_1, \Delta b_1, \Delta c_1)$, $(\Delta a_2, \Delta b_2, \Delta c_2)$, and $(\Delta a_3, \Delta b_3, \Delta c_3)$ are presented in Appendix 2. Because these are the total corrections for the joints, a proper distribution method has to be designed to apply these corrections to each individual joint. In GEBOD, Δa_1, Δb_1, and Δc_1 are distributed to the joints above the hip joint according to the ratio of the absolute value of each joint's z coordinate to the seated height. The ratio is based on the 50th %tile adult male and female and assumed to be the same for the other sizes. Because the amount of the adjustment of the coordinates is small, usually less than 5%, this assumption is acceptable and can simplify the numerical calculation. The resulting joint location regression equation for any joint above the hip is as follows:

$$Z_i = (a_i + f_i \Delta a_1) W + (b_i + f_k \Delta b_1) h_t + (c_i + f_i \Delta c_1) \tag{12}$$

where f_i is a proportional distributing factor. Similarly, Δa_2, Δb_2 and Δc_2 are distributed to the joints below the hip joint, and Δa_3, Δb_3, and Δc_3 are distributed to the arm joints. In this

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way, the modified set of joint regression equations has been
generated to satisfy both the seated height and standing height
requirements.

Ellipsoid Semiaxes

GEBOD uses the same formulae for the adult human options as the
child and user supplied options to compute the ellipsoid X and Y
semiaxes (Table 3). However, the Z semiaxis of each joint is
calculated based on the joint distance and a certain overlap
according to the radius of the joint sphere to give a proper
appearance. This method is similar to the method used for the
child and user supplied options and gives a cover between two
adjacent joints. It is illustrated in Figure 6.
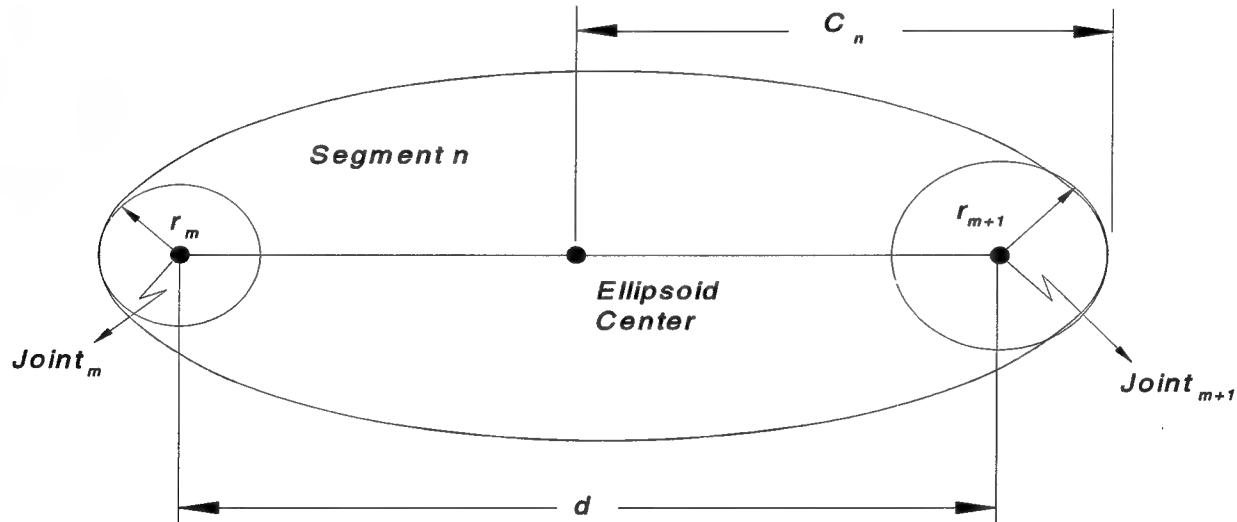
Figure 6 Ellipsoid Semiaxes

The Z semiaxis of segment n is:

$$C_n = \frac{1}{2}(d + r_m + r_{m+1})$$ (13)

where C_n is the Z semiaxis, d is the distance between two joints

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and r_m is the radius of the ith joint sphere listed in Figure 4. This approach also gives a smooth intersection between adjacent ellipsoids preventing any sticking out at the tip of the ellipsoid.

The foot X semiaxis is defined as half of the ankle height. Because the ankle height in the male survey was measured at the level of minimum circumference, this results in unreasonably large feet. Therefore the ankle height is recalculated at the level of the lateral medial malleolus landmark, which corresponds to the measurement taken in the female study, resulting in a better foot appearance.

Ellipsoid Center Locations

The ellipsoid center location is defined as the offset of the ellipsoid center from the mass center of the segment, and is presented as three-dimensional coordinates in the segment's local reference system. The X and Y coordinates of the adult human ellipsoid center locations are calculated in the same way as for the child and user-supplied options. Referring to Figure 7, the Z offset of the ellipsoid for the adult humans can be given as follows:

$$Z_{off} = Z_m + r_m - C_n \qquad \textbf{(14)}$$

where r_i and C_n have the same meanings as in Eq. (13). Z_{off} is the Z coordinate of the offset and Z_m is the Z coordinate of the mth joint, both coordinates in the segment's local reference system. In Figure 7, C.G. is the center of mass and C.E. is the geometric center of the ellipsoid.

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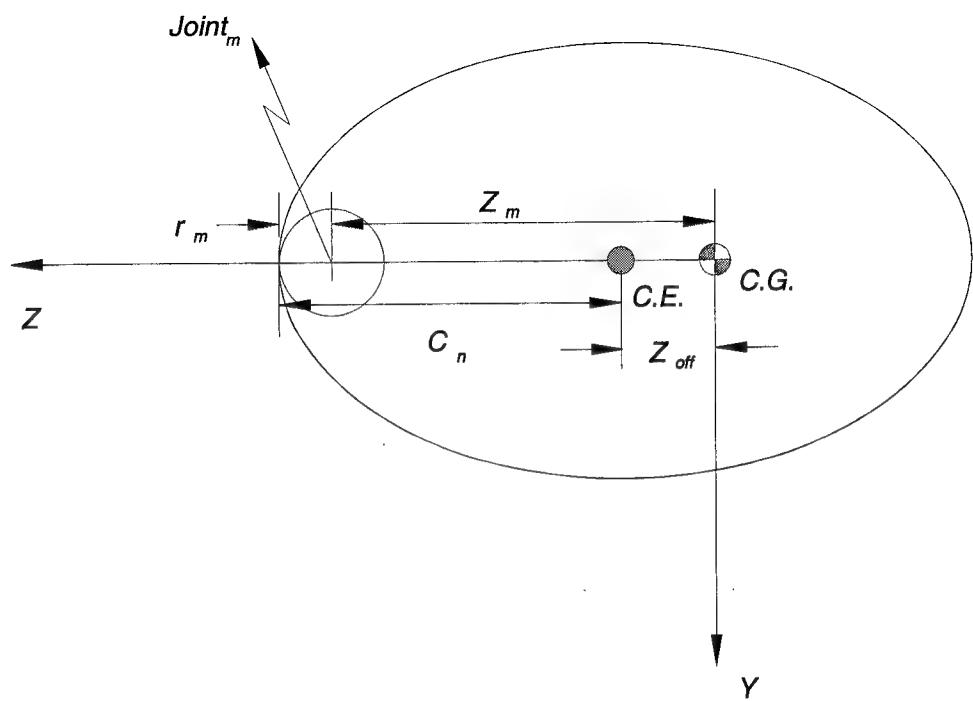
Figure 7 Ellipsoid Center Location

Inertial Properties of Body Segments

The inertial properties of a body refer to its mass, principal
moments of inertia and associated directions, and the center of
gravity location. The ATB model requires direct input of the
mass and principal moments of inertia of each segment, as well as
the directions of the principal moments, relative to the local
reference axes. Use of local reference axis systems, which are
located at the segment centers of gravity, to specify joint
locations indirectly locates the segment center of gravity.
Thus, direct input of center of gravity locations to the ATB
model is not necessary.

The distribution of mass within the human body greatly affects
the inertial properties. For simplicity, it is assumed that the
human body is homogeneous, and thus, each individual body segment

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is homogeneous and has the same density as does all the other body segments.

Child and User-Supplied Options

For the child and user-supplied options, GEBOD determines inertial properties of the head, neck, upper and forearms, and thighs and calves by calculating the inertial properties of that segment's contact ellipsoid. These inertial properties are then taken as approximations to the inertial properties of the segment.

For the torso segments and the feet, GEBOD uses a techniques similar to that developed by Leet (Ref 18). This involves modeling a segment by a right elliptical solid that satisfies two criteria:

1. Each horizontal cross section (parallel to the local reference XY plane) is an ellipse,
2. The center of each of these elliptical cross sections lies on the Z local reference axis.

The inertial properties of this model are then calculated and taken as approximations to the inertial properties of the segment.

The right elliptical solid used for the torso segments is illustrated in Figure 8a. It consists of four pieces. The top is a semi-ellipsoid. Below this are two elliptical frustrums. The bottom of the shape consists of another semi-ellipsoid. The right and left feet use identical shapes which are elliptical frustrums. The dimensions of the frustrums and ellipsoids used in these shapes are determined from the body dimension data as indicated in Figures 8a and 8b.

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(a)
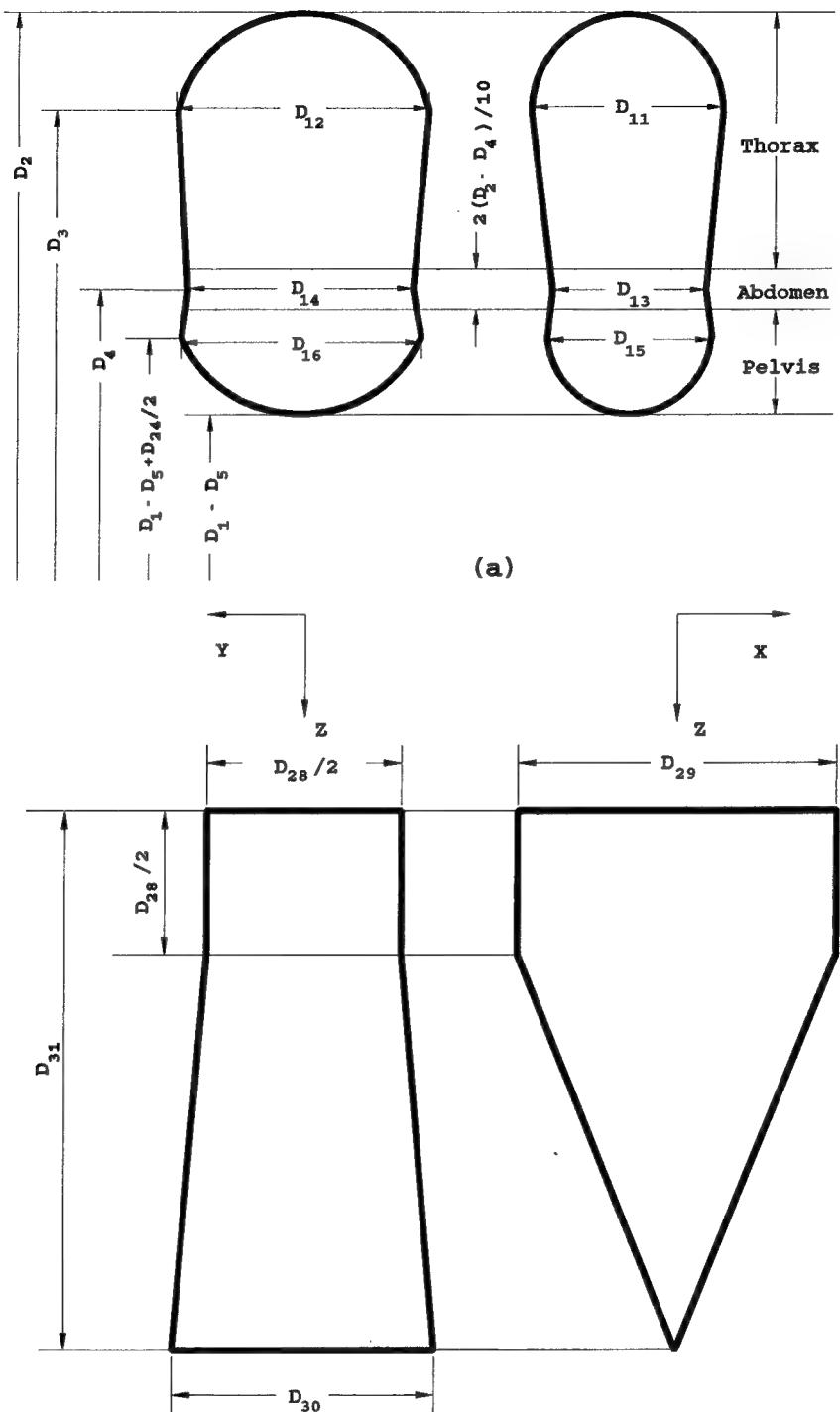
(b)

Figure 8   Cross Sections of Right Elliptical Solids Used
to Approximate Segment Inertial Properties for
Child and User-Supplied Options
(a)   Solid Used with Thorax Segments
(b)   Solid Used with Feet Segments

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Numerical integration is used to compute the inertial properties of the right elliptical solids. Successive approximations are made of the shapes by stacks of elliptical cylinders. Within each approximation, all cylinders are of the same height. Each successive approximation uses more cylinders of a lesser height than the previous. After each approximation, the combined volume of all cylinders within the stack is compared to the combined volume of the previous stack. When the difference between these two volumes drops below a specified tolerance level, the inertial properties of the combined stack of cylinders are taken as the inertial properties of the right elliptical solid. These inertial properties are then used as approximations to the inertial properties of the segment in question.

The combined volume of all shapes used to determine inertial properties (both ellipsoids and right elliptical solids) is computed, and a density is determined so that the total mass of these segments will equal the desired total body mass (D_0). The ratio of this density to the density of water (which approximates average human body density) is listed in the tabular output file as a weight correction factor.

The centers of gravity of the shapes used to approximate segment inertial properties are taken by GEBOD as the true locations of the segment centers of gravity for the child and user-supplied options. In developing expressions for the joint locations, the origins of the local reference systems (i.e., segment center of gravity) were approximated by the contact ellipsoid centers. Once GEBOD has developed the shapes for inertial properties, the joint location coordinates must be adjusted to account for the translation of axes from the contact ellipsoid center to the center of gravity of the shape used to compute inertial properties. Since an ellipsoid is completely symmetrical, its center of gravity is located at its center, which agrees with the assumed location of the local reference systems. The right

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elliptical solids, however, are only symmetric about the Z axis. So, in general, the location of the center of gravity of this shape does not correspond with its center in the Z direction. The torso and feet segments, which use this shape in computing their inertial properties, are the only segments in which the center of gravity does not coincide with the center of the contact ellipsoid. Because this moves the location of the local reference system of these segments in the Z direction, the Z coordinates of the joints located relative to these segments are adjusted for this change, after computation of inertial properties.

Adult Human Options

In the stereophotometric studies, the stereophotometric data of the surface points of each female and male subject were used to calculate the volume of each segment. The volumes were used to generate a group of regression equations to predict segment volumes for the adult human female and male subject type options. The estimated volumes are transformed to weights using the relationship, weight (slugs) = volume (in^3) * density (slugs/in^3), where density is a constant 1.12287E-3. The segment weights are then converted to pounds and adjusted so that their sum equals the total body weight.

The principal moments of inertia were also calculated from the stereophotometric segment volumes for each female and male subject. These data were used to generate regression equations to predict each segment's principal moments of inertia for the adult human female and male subject type options. The more detailed information about this process can be found in references 8 and 9. Mean principal axes orientations for both the adult male and female subject type options were determined with respect to the local axes and used for all subjects.

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Joint Characteristics

The ATB model uses several types of joints, such as ball joint, pin joint and Euler joint. These joints can be subject to spring torque, coulomb friction, and viscous torque. Some of them may be either free or locked in certain states. The joint may also have elastic, viscous, and joint stop characteristics. These characteristics were obtained from a number of sources, including Engin and Chen (Ref 19), and adjusted to provide physically realistic ATB model results. For the joints that did not have a complete set of properties available, the characteristics were estimated based on data from the other joints.

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APPENDIX A
Body Dimension Descriptions

These are general descriptions to be used in determining the dimensions for the body dimension input file. Descriptions of the specific measurements used from the anthropometric surveys can be found in Reference 4.

0. WEIGHT: Subject stands on scales (nude or wearing lightweight undergarments) with feet parallel and weight distributed equally on both feet.

1. STANDING HEIGHT: Subject stands erect, head in the Frankfort plane, heels together, and weight distributed equally on both feet. With the arm of the anthropometer firmly touching the scalp, measure the vertical distance from the standing surface to the top of the head.

2. SHOULDER HEIGHT: Subject stands erect looking straight ahead, heels together, and weight distributed equally on both feet. With an anthropometer, measure the vertical distance from the standing surface to the right acromiale landmark.

3. ARMPIT HEIGHT: Measurement derived by subtracting Scye Circumference divided by π from Shoulder Height (see above).

> Scye Circumference: Subject stands erect looking straight ahead. The right arm is abducted sufficiently to allow placement of a tape into the axilla. With a tape passing through the axilla, over the anterior and posterior-vertical scye landmarks and over the right acromiale landmark, measure the circumference of the scye. The axillary tissue is not compressed.

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4. WAIST HEIGHT: Subject stands erect, his head in the
    Frankfort plane. Using an anthropometer, measure the
    distance from the standing surface to the omphalion
    landmark. The subject must not pull in his stomach.

5. SEATED HEIGHT: Subject sits erect, head in the Frankfort
    plane, upper arms hanging relaxed, forearms and hands
    extended forward horizontally. With the anthropometer arm
    firmly touching the scalp, measure the vertical distance
    from the sitting surface to the top of the head.

6. HEAD LENGTH: Subject sits. With a spreading caliper,
    measure in the midsagittal plane the maximum length of the
    head between the glabella landmark and the occiput.

7. HEAD BREADTH: Subject sits. With a spreading caliper
    measure the maximum horizontal breadth of the head above the
    level of the ears.

8. HEAD TO CHIN HEIGHT: Subject stands under the headboard
    looking straight ahead. The headboard is adjusted so that
    its vertical and horizontal planes are in firm contact with
    the back and the top of the head. Positioning the head in
    the Frankfort plane and using the special gauge, measure the
    vertical distance from the horizontal plane to the menton
    landmark.

9. NECK CIRCUMFERENCE: Subject sits erect, head in the
    Frankfort plane. A piece of dental tape is placed around
    the neck, passing over all four neck landmarks. The
    measurer marks off with her thumbnail a length of tape
    corresponding to the subject's neck circumference, and then
    measures this tape segment with a standard tape.

10. SHOULDER BREADTH: Subject sits erect looking straight ahead, upper arms hanging relaxed, forearms and hands extended forward horizontally. With a beam caliper, measure the distance between the acromiale landmarks.

11. CHEST DEPTH: Subject stands erect looking straight ahead, heels together, and weight distributed equally on both feet. With a beam caliper, measure the horizontal depth of the trunk at the level of the bustpoint landmarks. The reading is made at the point of maximum quiet inspiration.

12. CHEST BREADTH: Subject stands erect looking straight ahead with arms slightly abducted. With a beam caliper, measure the horizontal distance across the trunk at the level of the bustpoint landmarks.

13. WAIST DEPTH: Subject stands erect looking straight ahead, arms at sides, heels together, and weight distributed equally on both feet. With a beam caliper, measure the horizontal depth of the trunk at the level of the waist landmarks. The reading is made at the point of maximum quiet inspiration. The subject must not pull in her stomach.

14. WAIST BREADTH: Subject stands erect looking straight ahead with arms slightly abducted. With a beam caliper, measure the horizontal breadth across the trunk at the level of the waist landmarks.

15. BUTTOCK DEPTH: Subject stands erect, heels together and weight distributed equally on both feet. With a beam caliper, measure the horizontal depth of the trunk at the level of the buttock landmark.

16. HIP BREADTH, STANDING: Subject stands erect, heels together and weight distributed equally on both feet. With a beam caliper, measure the maximum horizontal breadth of the hips.

17. SHOULDER TO ELBOW LENGTH: Subject stands erect looking straight ahead and with arms relaxed. With a beam caliper held parallel to the long axis of the right upper arm, measure the distance from the acromiale landmark to the radiale landmark.

18. FOREARM-HAND LENGTH: Measurement derived by summing Radiale-Stylion Length and Hand Length.

    Radiale-Stylion Length: Subject stands erect with arms relaxed. With a beam caliper held parallel to the long axis of the right forearm, measure the distance from the radiale landmark to the stylion landmark.

    Hand Length: Subject sits, right forearm and hand raised with palm up. The fingers are together and straight but not hyper-extended. With the bar of a sliding caliper parallel to the long axis of the hand, measure the distance from the wrist landmark to the dactylion.

19. BICEPS CIRCUMFERENCE: Subject stands with right arm slightly abducted. With a tape held in a plane perpendicular to the long axis of the upper arm, measure the circumference of the arm at the level of the biceps landmark.

20. ELBOW CIRCUMFERENCE: Subject stands, right upper arm raised so that its long axis is horizontal, elbow flexed 90 degrees, fist tightly clenched and biceps strongly contracted. With a tape passing over the tip and through

the crotch of the elbow, measure the circumference of the
elbow.

21. FOREARM CIRCUMFERENCE: Subject stands erect with right arm
slightly abducted and hand relaxed. With a tape held in a
plane perpendicular to the long axis of the forearm, measure
the circumference of the arm at the level of the forearm
landmark.

22. WRIST CIRCUMFERENCE: Subject stands with right arm slightly
abducted. With a tape held in a plane perpendicular to the
long axis of the forearm and hand, measure the circumference
of the wrist at the level of the stylion landmark.

23. KNEE HEIGHT, SEATED: Subject sits with his feet resting on
a surface adjusted so that the knees are bent at about right
angles. Using an anthropometer, measure the vertical
distance from the footrest surface to the suprapatella
landmark on the right knee.

24. THIGH CIRCUMFERENCE: Subject stands erect, heels
approximately 10 cm apart, and weight distributed equally on
both feet. With a tape held in a plane perpendicular to the
long axis of the right thigh measure the circumference of
the thigh at the level of the lowest point on the gluteal
furrow. Where the furrow is deeply indented, the
measurement is made just distal to the furrow.

25. UPPER LEG CIRCUMFERENCE: Measurement derived by summing the
Thigh Circumference (see above) and the Knee Circumference
(see below) and dividing the sum by two to obtain the
average.

26. KNEE CIRCUMFERENCE: Subject stands erect, heels
approximately 10 cm apart, and weight distributed equally on

both feet. With a tape held in a plane perpendicular to the long axis of the right leg, measure the circumference of the knee at the level of the midpatella landmark. The subject must not tense her knee during the measurement.

27. CALF CIRCUMFERENCE: Subject stands erect, heels approximately 10 cm apart, and weight distributed equally on both feet. With a tape held in a plane perpendicular to the long axis of the right lower leg, measure the circumference of the calf at the level of the calf landmark.

28. ANKLE CIRCUMFERENCE: Subject stands erect with weight distributed equally on both feet. With a tape held in a plane perpendicular to the long axis of the right lower leg, measure the circumference of the leg at the level of the ankle landmark.

29. ANKLE HEIGHT, OUTSIDE: Subject stands with weight distributed equally on both feet. With the special measuring block, measure the vertical distance from the standing surface to the lateral malleolus landmark on the right leg.

30. FOOT BREADTH: Subject stands erect, right foot in the measuring box, left foot on a board of equal height, and weight distributed equally. The right foot is positioned so that its long axis is parallel to the side of the box, the heel touches the rear of the box, and the medial metatarsal-phalangeal joint touches the widest part of the foot, measure on the scale of the box the breadth of the foot.

31. FOOT LENGTH: Subject stands erect, right foot in the measuring box, left foot on a board of equal height, and weight distributed equally. The right foot is positioned so that its long axis is parallel to the side of the box, the

heel touches the rear of the box, and the medial metatarsal-phalangeal joint touches the side of the box. With the measuring block touching the tip of the most protruding toe, measure on the scale of the box the length of the foot.

APPENDIX B
Joint Location Corrections

A complete list of joint regression equations used in GEBOD for all options can be found in References 3 and 4. The coefficients for all the regression equations are also contained in the BLOCK DATA section of the program as described in Appendix 3. This appendix gives the regression equations for the joint location corrections used in the human adults options. They refer to the total amount of corrections. W and H stand for total body weight and standing height, respectively.

GEBOD stores the coefficients of regression equations in a matrix form. A matrix **R** (2 x 40) consisting of the distributing factors, f_i, and another matrix **D** (14 x 2) containing the coefficient corrections, Δa_2, Δb_2, and Δc_2, are constructed to calculate the final joint regression equation coefficient matrix G_{new} (14 x 40) in the GEBOD program. The relationships are as follows:

$$G_{new} = G + DR \qquad\qquad (15)$$

where **G** is the original joint regression equation coefficient matrix. The arms joints are similarly constrained by the arm length.

(1) Above hip joint (for seated height constraints)
female:   correction = 0.000757 * W - 2.084770
          correction = 0.024580 * H - 3.892919
          correction =-0.019198 * W + 0.103563 * H - 6.392921
male:   correction =-0.033833 * W + 4.306696
          correction =-0.001928 * H - 1.261201
          correction =-0.033677 * W + 0.204725 * H -9.924997

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(2) **Below hip joint (for standing height constraints)**

female: correction = 0.033702 * W - 3.605820

             correction =-0.052777 * H + 3.623647

             correction = 0.016812 * W - 0.123793 * H + 5.903415

male: correction =-0.237030 * W + 3.964718

             correction =-0.004937 * H + 0.436674

             correction = 0.037725 * W - 0.243725 * H + 10.664086

(3) **Arm length corrections**

female: correction =-0.004889 * W - 2.462996

             correction =-0.069926 * H + 0.989450

             correction =-0.019235 * W + 0.010856 * H - 1.601085

male: correction =-0.037079 * W + 4.039917

             correction =-0.050387 * H + 1.312703

             correction =-0.023724 * W + 0.086645 * H -4.179244

APPENDIX C
Descriptions of Block Data and Subroutines Used in GEBOD

Routines (in order of appearance):

PROGRAM GEBOD
BLOCK DATA

1. SUBROUTINE DIALOG
2. SUBROUTINE ASKUN
3. SUBROUTINE PTILE
4. SUBROUTINE NDTRI
5. SUBROUTINE ACONTAC
6. SUBROUTINE BCONTAC
7. SUBROUTINE ASEGMAS
8. SUBROUTINE BSEGMAS
9. SUBROUTINE ASGINER
10. SUBROUTINE BSGINER
11. SUBROUTINE ELLIP
12. ENTRY ELLPMI
13. SUBROUTINE TORSO
14. SUBROUTINE FEET
15. SUBROUTINE ARESULTS
16. SUBROUTINE BRESULTS
17. SUBROUTINE CNVRT
18. SUBROUTINE CRESULTS
19. SUBROUTINE ATBOUT
20. SUBROUTINE NOATBOUT
21. SUBROUTINE MATVEC
22. FUNCTION FNAME

BLOCK DATA DESCRIPTION

REGEQ(j,i)
Regression equation coefficients used to compute body dimensions.

  i = -1   Age equation
  i = 0   Weight equation
  i = 1 to 34   Body dimension equations
  j = 1 to 10   Coefficients of regression equations for
                   child subject
  j = 11 to 17   Coefficients of regression equations for
                   adult female subject
  j = 18 to 24   Coefficients of regression equations for
                   adult male subject

JNTEQ(j,i)
Regression equation coefficients used to compute joint locations.

  i = 1 to 55   Joint coordinate equation of each joint in x,
                   y and z directions.
  j = 1 to 7   Coefficients of regression equations for
                   adult female subject
  j = 8 to 14   Coefficients of regression equations for
                   adult male subject

MOMEQ(j,i)
Regression equation coefficients used to compute principal
moments of inertia of segments.

  i = 1 to 36   Principal moment of inertia equation of each
                   segment in x, y and z directions
  j = 1 to 7   Coefficients of regression equations for
                   adult female subject
  j = 8 to 14   Coefficients of regression equations for
                   adult male subject

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VOLEQ(j,i)

Regression equation coefficients used to compute volumes of segments.

     i = 1 to 11   Volume regression equation of each segment

     j = 1 to 7   Coefficients of regression equations for adult female subject

     j = 8 to 14   Coefficients of regression equations for adult male subject

DIFREG(j,i)

Regression equation coefficients used to compute the difference of seated and standing heights between the sum of the stereophotometric joint locations and the body dimension results.

     i = 1   Regression equation representing seated height difference

     i = 2   Regression equation representing standing height difference

     j = 1 to 7   Coefficients of regression equations for adult female subject

     j = 8 to 14   Coefficients of regression equations for adult male subject

DIFARM(j)

Regression equation coefficients used to compute the difference of the arm length between the sum of the stereophotometric joint locations and the body dimension results.

     j = 1 to 7   Coefficients of regression equations for adult female subject

     j = 8 to 14   Coefficients of regression equations for adult male subject

FFEMLE(j,i)

Multiplication factors used to distribute the height difference
proportionally among the joints for adult female subjects.

      i = 1 to 40   Corresponding to index i in JNTEQ

      j = 1   Factors for adjusting the seated height

      j = 2   Factors for adjusting the standing height

FMALE(j,i)

Multiplication factors used to distribute the height difference
proportionally among the joints for adult male subjects.

      i = 1 to 40   Corresponding to index i in JNTEQ

      j = 1   Factors for adjusting the seated height

      j = 2   Factors for adjusting the standing height

SUBROUTINE DESCRIPTIONS

1. Subroutine DIALOG(IPTR, ICNT, JPTR, JCNT, ISTRT, ISUB, NSEGS)

DIALOG writes prompts to the console and accepts input from the
console describing the subject for which body description data is
to be produced. The subject parameters, IPTR, ICNT, JPTR, JCNT,
ISTRT, ISUB, and NSEGS are returned to the main routine
specifying the choices made by the user.

IPTR   Specifies row of REGEQ containing first regression
          equation coefficient to be used. IPTR is set to 25 for
          user supplied dimensional data.

ISUB   Specifies the subject type.

          ISUB=1:   child subjects

          ISUB=2:   adult female subjects

          ISUB=3:   adult male subjects

          ISUB=4:   user supplied data subjects

ICNT   Number of coefficients in the regression equation to be
          used.

JPTR Specifies row of JNTEQ, MOMEQ, and VOLEQ containing first regression equation coefficient to be used for ISUB=2 or ISUB=3.

JCNT Number of coefficients in JNTEQ, MOMEQ, and VOLEQ regression equation to be used.

ISTRT First body dimension to be generated:

    ISTRT = -1 (AGE) for child subjects.

    ISTRT = 0 (WEIGHT) for adult subjects or user supplied data.

NSEGS Number of segments generated for ISUB=2 or ISUB=3.

PRED Values of predicting variables to be used with REGEQ.

2. Subroutine ASKUN(VARB, UNITS, ICHOS, ICNT)

ASKUN asks user choice of units to be used with some input variable or the output of results. The parameters are the following:

VARB Character string describing what units are to be selected for.

UNITS Units available to choose from.

ICHOS Returns which of the units was chosen.

ICNT Number of different units available to choose from.

3. Subroutine PTILE(ISUB, IDIM, PRED)

PTILE computes a percentile point, specified by the user, of a body dimension used as a predictor, by assuming the dimension is normally distributed.

ISUB Specifies subject type, and thus which position of the mean and standard arrays to use.

IDIM The dimension which a percentile point is to be computed for.

PRED Returns the computed percentile point.

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4. Subroutine NDTRI(P, X, D, IE)

NDTRI computes X (The output argument such that P=the probability that U, the random variable, is less than or equal to X), D (The output density, F(X)), and IE (The output error code) using P (The input probability).

5. Subroutine ACONTAC

ACONTAC computes joint locations and contact ellipsoid semiaxes for ISUB=1 (child) or ISUB=4 (user-supplied body dimensions), given in the local axes systems. The centers of ellipsoids in the global coordinates are also computed in this subroutine. The computation is only based on the regression equations of body dimensions. The stereophotometric regression results for joint locations are not available in these two options. Therefore, they are determined by body dimensions.

DD(i) The body dimensions generated from the regression equations based on user input weight and standing height values. i=1,32 represent 32 body dimensions defined in Reference 3. DD(i) is computed in the main program by using regression equation data REGEQ (i,j).

RNJ(i,j) The x, y, z coordinates of joint locations with respect to the geometric center of the corresponding ellipsoid. i=1,2,3 stands for the x, y, and z coordinates of a joint. j=1 to 30 represent each joint in the order of ATB model joint number definition and from left to right. RNJ(i,j) are calculated from DD(i).

AN(i) The x semiaxes of the segment contact ellipsoids. i=1 to 15 represent 15 segments. AN(i) is computed from DD(i) also.

BN(i) The y semiaxes of the segment contact ellipsoids.

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CN(i)   The z semiaxes of the segment contact ellipsoids.
XYZCG(i,j)   The global locations of the segment centers.
                  i=1,15 represent segments, and j=1,2,3 represent
                  x, y and z coordinates.
MATRIX(i,j)   Transformation cosine matrix from the anatomical
                  axis system to the local axis system (i=1,4,
                  j=1,4).

6. Subroutine BCONTAC

BCONTAC computes the joint locations, contact ellipsoid semiaxes
and ellipsoid centers for ISUB=2 (adult female) or ISUB=3 (adult
male). The computation is based on the regression equations of
the body dimensions plus the regression equations of the joint
locations. All the coordinates are given in the local axes
systems whose origins are located at the mass centers of the
segments. Height constraints are applied during the joint
locations calculations to correspond with the body dimension
results. The ellipsoid centers are mainly determined by the
joint locations. The parameters, JPTR, JCNT, NSEGS, and ISUB are
initialized in subroutine DIALOG.

DD(i), AN(i), BN(i), CN(i), and MATRIX(i,j) are the same
variables as used in subroutine ACONTAC, except that they also
contain the hand dimensions and wrist locations if the user
selects the 17 segment option.

RNJNEW(i,j)   The joint location regression equations after
                  applying height constraints.
RNJ(i,j)   Similar to RNJ(i,j) used in ACONTAC. However, in
                  BCONTAC, RNJ(i,j) is computed by using regression
                  equations and is given with respect to the mass
                  center of the corresponding segment.

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XYZCG(i,j)   Similar to XYZCG(i,j) used in ACONTAC. However,
                    in BCONTAC, XYZCG(i,j) is given with respect to
                    the mass center of the segment.

7. Subroutine ASEGMAS

ASEGMAS computes approximate segment masses by calling subroutine
ELLIP. WTCOR is then computed to adjust the body density, DENS,
so that the total body mass agrees with DD(0) (input body
weight). Segment masses are then recomputed using WTCOR. In
this subroutine, the joint coordinates (on torso and feet) are
adjusted to the change in the local reference system due to the
difference between the center of the ellipsoid and the mass
center locations of the corresponding segment after computing the
inertial properties. This subroutine is used for ISUB=1 or
ISUB=4 only.

ZEE(i)   Contains z coordinate giving the vertical extent of the
            cylinders that are used to approximate the right
            elliptical solids for the inertial properties
            computation.
RMN(i)   Segment masses computed from subroutine ELLIP. i is the
            segment number.
SUMM   Total mass of the body.
ZCG(i)   The same variable of XYZCG (i) in subroutine ACONTAC.
CGZ(i)   z coordinate of the center of gravity of the segment.
WTCOR   Eight correction factors used to adjust DENS.

8. Subroutine BSEGMAS

BSEGMAS computes the approximate segment masses for ISUB=2 or
ISUB=3. The masses are directly computed from volume regression
equations instead of using subroutine ELLIP. The parameters, JPTR,
JCNT, and NSEGS, are initialized in subroutine DIALOG. RMN(i),
SUMM, DENS and WTCOR are the same as those used by ASEGMAS.

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VOLVAL(i) Segment volume values.

9. Subroutine ASGINER

ASGINER computes the segment moments of inertia for ISUB=1 or ISUB=4 by calling subroutine ELLPMI. See (Ref 3).

PHI(i,j) . Principle moment of inertia of segment j. i=1,2,3 represents x, y and z directions in local reference system.

10. Subroutine BSGINER

BSGINER computes segment moments of inertia for ISUB=2 or ISUB=3 by using regression equations of moment of inertia.

PHI(i,j) is same as those used in ASGINER.

11. Subroutine ELLIP(ISEG, IABEVAL, TMASS)

ELLIP computes the mass and center of gravity location of a right elliptical solid. Numerical integration is used to compute the inertial properties of the right elliptical solids. Successive approximations are made to the model by stacks of elliptical cylinders whose inertial properties are taken as the inertial properties of the right elliptical solid after reaching the specified tolerance. This subroutine is used only for options ISUB=1 or ISUB=4.

ISEG   Specifies segment being modelled by a right elliptical solid.

IABEVAL   Specifies subroutine to be used to compute semiaxes of the solid at specific z heights.

           IABEVAL=1   TORSO
           IABEVAL=2   FEET

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TMASS   Returns the mass computed for the solid.

12. Entry ELLPMI(ISEG, IABEVAL, MI)

ELLPMI computes the moments of inertia of a right elliptical
solid, based on the numerical integration determined by
subroutine ELLIP. The first two parameters are the same as those
used by ELLIP. The third, MI, returns the moment of inertia of
the solid. This subroutine is only used by ISUB=1 or 4.

MASS   Mass of the right elliptical solid.

13. Subroutine TORSO(Z, X, Y)

TORSO computes the semiaxis values for the right elliptical model
of the three torso segments. It is used by options ISUB=1 or 4.

Z   Vertical location at which the semiaxes are to be
          computed.
X   Returns x semiaxis.
Y   Returns y semiaxis.
H2   Top of solid
H3   Break between top semi-ellipsoid and top frustrum
H4   Break between two frustrums
H5   Break between bottom frustum and bottom semi-ellipsoid

14. Subroutine FEET(Z, X, Y)

Feet computes semiaxis values for the right elliptical model of
the feet. It is used only by options ISUB=1 or 4.
Z, X and Y are the same as those used in TORSO.

H2   Top of solid
H1   Break between elliptical cylinder and frustrum
H0   Bottom of solid

15. Subroutine ARESULTS

ARESULTS writes out the computed body description data for 15 segments. The following parameters are output as arrays:

JNT(i)
: Pointer array for associating joints with segments. i=1,14 are the the joint numbers.

YPRLL(i,j)
: Yaw, pitch, and roll angles of the local reference axes of the segment to specify the axes of joints. i=1,14 are the joint numbers. j=1,3 are the angles about the local reference axes of segment No. JNT(i). j=4,6 are the angles about the local reference axes of segment No. i+1.

IPIN(i)
: Specifies joint type. i=1,14 are the of joint numbers.

SUBTYP
: Description to user of 4 sources of body dimension data.

DIMLAB(i)
: Names of the body dimensions, i=1,31.

SEGLAB(i)
: Segment labels, i=1,15.

JNTLAB(i)
: Joint labels, i=1,14.

PLTSYM(i)
: Plotting symbol for segments and joints, i=1,15.

SPRING(i,j)
: Joint spring characteristics, i=1,14, j=1,10.

SEGTEST(i,j)
: Integration convergence test parameters, i=1,12, j=1,2.

VISC(i)
: Joint viscous characteristics, i=1,14.

A(i),B(i),C(i)
: Ellipsoid semiaxes of x, y, and z, i=1,15.

RMN(i)
: Segment mass, i=1,15.

PHI(i,j)
: Segment moment of inertia, i=1,3 represent x, y, z directons. j=1,15 are segment No.s.

FYPRPMI(i,j)
: Yaw, pitch, and roll angles of the principle axes relative to the local

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	reference axes for adult female subjects, i=1,15, j=1,3.
MYPRPMI(i,j)	Yaw, pitch, and roll angles of the principle axes relative to the local reference axes for adult male subjects, i=1,15, j=1,3.
XCG(i),YCG(i),ZCG(i)	x, y, and z coordinates of the segment contact ellipsoid centers in the local reference system, i=1,15.

16. Subroutine BRESULTS

BRESULTS writes out the computed body description data for 17 segments. The output parameters are similar to ARESULTS.

17. Subroutine CNVRT(IUN, SPRING)

CNVRT converts all output data to the units selected by the user

IUN	Conversion index. IUN > 1 will convert output to the metric system
SPRING	Joint spring characteristics
CONV	Conversion factors for converting body dimensions from metric to English units

18. Subroutine CRESULTS(ISUB)

CRESULTS writes out the computed body description data for ISUB > 4 (dummy data sets). The output parameters are similar to BRESULTS

19. Subroutine ATBOUT(IUN)

ATBOUT writes out the body description data for ISUB > 4 in readable format and ATB input format. The output parameters are similar to BRESULTS.

20. Subroutine NOATBOUT(IUN)

NOATBOUT writes out the body description data for ISUB > 4 in readable format but not ATB input format.

21. Subroutine MATVEC(A, B, C)

MATVEC performs matrix multiplication C = AB where A(3,3) is a matrix, and B(3) and C(3) are vectors

22. CHARACTER*42 Function FNAME(F, E)

FNAME concatenates the extension, E, to filename, F.

Appendix D
Example GEBOD Output

Extension .AIN file

```
    17    16        Adult Human Male                             CARD B.1
LT   1 24.870.92020.84511.0672 4.718 6.942 4.322-0.472 0.000 0.885   1  CARD B.2
              0.00   0.00    0.0
CT   2  5.100.14480.08090.2189 4.389 6.092 3.341-1.463 0.000 0.105   1 .CARD B.2
              0.00   0.00    0.0
UT   3 52.874.35863.21112.7229 4.826 6.451 7.122 0.000 0.000-0.136   1  CARD B.2
              0.00  14.40    0.0
N    4  2.260.01540.01850.0231 2.402 2.402 4.384-0.480 0.000 1.179   1  CARD B.2
              0.00   0.00    0.0
H    5  9.290.18080.20630.1340 3.912 3.071 5.683-1.118 0.000 0.000   1  CARD B.2
              0.00  36.00    0.0
RUL  6 21.030.26670.26540.0154 3.054 3.05411.749 0.000-0.327 0.518   1  CARD B.2
              0.00   0.00    0.0
RLL  7  8.230.51180.51960.0600 2.329 2.32910.277 0.932-1.152 0.903   1  CARD B.2
              0.00   0.00    0.0
RF   8  2.060.03970.03760.0072 1.390 1.922 5.323-0.016-0.659 0.000   1  CARD B.2
             -4.00   8.40   -6.1
LUL  9 21.030.26670.26540.0154 3.054 3.05411.749 0.000 0.327 0.518   1  CARD B.2
              0.00   0.00    0.0
LLL  A  8.230.51180.51960.0600 2.329 2.32910.277 0.932 1.152 0.903   1  CARD B.2
              0.00   0.00    0.0
LF   B  2.060.03970.03760.0072 1.390 1.922 5.323-0.016 0.659 0.000   1  CARD B.2
              4.00   8.40    6.1
RUA  C  4.210.11410.12130.0236 1.973 1.973 6.602 0.000-0.220-0.588   1  CARD B.2
              0.00   0.00    0.0
RLA  D  2.950.07550.07730.0113 1.764 1.764 6.012 0.000 0.452 0.857   1  CARD B.2
              0.00   0.00    0.0
RH   E  1.100.01150.00940.0037 0.543 1.750 4.310 0.000 1.107 0.592   1  CARD B.2
            -14.00   6.00   -7.7
LUA  F  4.210.11410.12130.0236 1.973 1.973 6.602 0.000 0.220-0.588   1  CARD B.2
              0.00   0.00    0.0
LLA  G  2.950.07550.07730.0113 1.764 1.764 6.012 0.000-0.452 0.857   1  CARD B.2
              0.00   0.00    0.0
LH   H  1.100.01150.00940.0037 0.543 1.750 4.310 0.000-1.107 0.592   1  CARD B.2
             14.00   6.00    7.7
 P   G   1    0 -1.45   0.00 -2.24 -2.39   0.00   2.25             CARD B.3
              0.00   0.00   0.00   0.00   5.00   0.00              0 0 0
 W   H   2    0 -1.76   0.00 -0.83 -0.32   0.00   6.99             CARD B.3
              0.00   0.00   0.00   0.00   5.00   0.00              0 0 0
NP   K   3    0 -0.27   0.00 -7.26 -0.93   0.00   1.46             CARD B.3
              0.00   0.00   0.00   0.00  10.00   0.00              0 0 0
HP   L   4    0  1.01   0.00 -2.51  0.28   0.00   2.27             CARD B.3
              0.00   0.00   0.00   0.00  10.00   0.00              0 0 0
RH   M   1    0 -0.51   2.14  1.52 -0.32 -1.96  -7.55             CARD B.3
              0.00   0.00   0.00   0.00-45.00   0.00              0 0 0
RK   N   6    1 -0.23   0.38  9.80  0.67 -0.58  -6.91             CARD B.3
              0.00   0.00   0.00   0.00  60.00   0.00              0 0 0
RA   O   7    0  0.39  -0.76  9.78  1.37 -0.33  -2.76             CARD B.3
              0.00  90.00   0.00   0.00  10.00   0.00              0 0 0
LH   P   1    0 -0.51  -2.14  1.52 -0.32  1.96  -7.55             CARD B.3
              0.00   0.00   0.00   0.00-45.00   0.00              0 0 0
LK   Q   9    1 -0.23  -0.38  9.80  0.67  0.58  -6.91             CARD B.3
              0.00   0.00   0.00   0.00  60.00   0.00              0 0 0
LA   R  10    0  0.39   0.76  9.78  1.37  0.33  -2.76             CARD B.3
              0.00  90.00   0.00   0.00  10.00   0.00              0 0 0
RS   S   3    0 -0.96   6.57 -4.35  0.52 -0.22  -5.22             CARD B.3
              0.00   0.00   0.00   0.00 -4.10   0.00              0 0 0
RE   T  12    1 -0.64  -0.41  5.04 -0.53  0.23  -4.18             CARD B.3
              0.00   0.00   0.00   0.00-70.00   0.00              0 0 0
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RW U  13   0   0.36 -0.01   5.77   0.12   0.55  -2.62              CARD B.3
                0.00   0.00   0.00   0.00   0.00   0.00                 0 0 0
LS V   3   0  -0.96  -6.57  -4.35   0.52   0.22  -5.22              CARD B.3
                0.00   0.00   0.00   0.00  -4.10   0.00                 0 0 0
LE W  15   1  -0.64   0.41   5.04  -0.53  -0.23  -4.18              CARD B.3
                0.00   0.00   0.00   0.00-70.00   0.00                 0 0 0
LW X  16   0   0.36   0.01   5.77   0.12  -0.55  -2.62              CARD B.3
                0.00   0.00   0.00   0.00   0.00   0.00                 0 0 0
0.00 10.00   0.00   0.70        20.00   0.00 10.00   0.00   0.70    5.00CARD B.4
0.00 10.00   0.00   0.70        20.00   0.00 10.00   0.00   0.70   35.00CARD B.4
0.00  5.00   0.00   0.70        25.00   0.00 10.00   0.00   0.70   35.00CARD B.4
0.00  5.00   0.00   0.70        25.00   0.00 10.00   0.00   0.70   35.00CARD B.4
0.00 10.00   0.00   0.70        70.00   0.00  0.80   0.00   0.70   40.00CARD B.4
0.00  1.80   0.00   0.70        60.00   0.00  0.00   0.00   0.00    0.00CARD B.4
0.00  7.00   0.00   0.70        35.00   0.00 10.00   0.00   0.70   26.00CARD B.4
0.00 10.00   0.00   0.70        70.00   0.00  0.80   0.00   0.70   40.00CARD B.4
0.00  1.80   0.00   0.70        60.00   0.00  0.00   0.00   0.00    0.00CARD B.4
0.00  7.00   0.00   0.70        35.00   0.00 10.00   0.00   0.70   26.00CARD B.4
0.00 10.00   0.00   0.70       122.50   0.00 10.00   0.00   0.70   65.00CARD B.4
0.00  1.80   0.00   0.70        70.00   0.00  0.00   0.00   0.00    0.00CARD B.4
0.00  1.80   0.00   0.70        35.00   0.00  1.80   0.00   0.70   45.00CARD B.4
0.00 10.00   0.00   0.70       122.50   0.00 10.00   0.00   0.70   65.00CARD B.4
0.00  1.80   0.00   0.70        70.00   0.00  0.00   0.00   0.00    0.00CARD B.4
0.00  1.80   0.00   0.70        35.00   0.00  1.80   0.00   0.70   45.00CARD B.4
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.100              30.                                                  CARD B.5
0.01  0.01  0.01  0.01  0.01  0.01  0.10  0.10  0.10  0.10  0.10  0.01CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
0.01  0.01  0.01  0.00  0.00  0.00  0.10  0.10  0.10  0.00  0.00  0.00CARD B.6
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Extension .TAB file

Adult Human Male

ADULT HUMAN MALE

SELECTED BODY DIMENSIONS

WEIGHT	50.00	%-TILE
STANDING HEIGHT	50.00	%-TILE

COMPUTED BODY DIMENSIONS

0	WEIGHT	173.5	LB.
1	STANDING HEIGHT	69.82	IN.
2	SHOULDER HEIGHT	57.17	IN.
3	ARMPIT HEIGHT	51.11	IN.
4	WAIST HEIGHT	41.92	IN.
5	SEATED HEIGHT	36.69	IN.
6	HEAD LENGTH	7.823	IN.
7	HEAD BREADTH	6.142	IN.
8	HEAD TO CHIN HEIGHT	8.965	IN.
9	NECK CIRCUMFERENCE	15.09	IN.
10	SHOULDER BREADTH	16.03	IN.
11	CHEST DEPTH	9.653	IN.
12	CHEST BREADTH	12.90	IN.
13	WAIST DEPTH	8.778	IN.
14	WAIST BREADTH	12.18	IN.
15	BUTTOCK DEPTH	9.437	IN.
16	HIP BREADTH,STANDING	13.88	IN.
17	SHOULDER TO ELBOW LENGTH	14.16	IN.
18	FOREARM-HAND LENGTH	19.45	IN.
19	BICEPS CIRCUMFERENCE	12.40	IN.
20	ELBOW CIRCUMFERENCE	12.30	IN.
21	FOREARM CIRCUMFERENCE	11.08	IN.
22	WRIST CIRCUMFERENCE	6.924	IN.
23	KNEE HEIGHT,SEATED	21.96	IN.
24	THIGH CIRCUMFERENCE	23.15	IN.
25	UPPER LEG CIRCUMFERENCE	15.22	IN.
26	KNEE CIRCUMFERENCE	15.47	IN.
27	CALF CIRCUMFERENCE	14.64	IN.
28	ANKLE CIRCUMFERENCE	8.822	IN.
29	ANKLE HEIGHT,OUTSIDE	5.401	IN.
30	FOOT BREADTH	3.844	IN.
31	FOOT LENGTH	10.65	IN.
32	HAND BREADTH	3.500	IN.
33	HAND LENGTH	7.519	IN.
34	HAND DEPTH	1.086	IN.

WEIGHT CORRECTION FACTOR =   0.963

EXAMPLE

CRASH VICTIM PARAMETERS (3-D)

CARDS B.2

SEGMENT			WEIGHT	PRINCIPAL MOMENT OF INERTIA (LB-SEC**2-IN)			SEGMENT CONTACT ELLIPSOID SEMIAXIS (IN)			CENTER (IN)			PRINCIPAL AXES (DEG)		
I	SYM	PLOT	(LB.)	X	Y	Z	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
1	LT	1	24.867	0.9202	0.8451	1.0672	4.718	6.942	4.322	-0.472	0.000	0.885	0.00	0.00	0.00
2	CT	2	5.104	0.1448	0.0809	0.2189	4.389	6.092	3.341	-1.463	0.000	0.105	0.00	0.00	0.00
3	UT	3	52.875	4.3586	3.2211	2.7229	4.826	6.451	7.122	-0.480	0.000	-0.136	0.00	14.40	0.00
4	N	4	2.259	0.0154	0.0185	0.0231	2.402	2.402	4.384	-1.118	0.000	1.179	0.00	0.00	0.00
5	H	5	9.287	0.1808	0.2063	0.1340	3.912	3.071	5.683	0.000	0.000	0.000	0.00	36.00	0.00
6	RUL	6	21.028	0.2667	0.2654	0.0154	3.054	3.054	11.749	0.932	-0.327	0.518	0.00	0.00	0.00
7	RLL	7	8.234	0.5118	0.5196	0.0600	2.329	2.329	10.277	-0.016	-1.152	0.903	0.00	0.00	0.00
8	RF	8	2.058	0.0397	0.0376	0.0072	1.390	1.922	5.323	0.000	-0.659	0.000	-4.00	8.40	-6.10
9	LUL	9	21.028	0.2667	0.2654	0.0154	3.054	3.054	11.749	0.932	0.327	0.518	0.00	0.00	0.00
10	LLL	A	8.234	0.5118	0.5196	0.0600	2.329	2.329	10.277	-0.016	1.152	0.903	4.00	8.40	6.10
11	LF	B	2.058	0.0397	0.0376	0.0072	1.390	1.922	5.323	0.000	0.659	0.000	0.00	0.00	0.00
12	RUA	C	4.207	0.1141	0.1213	0.0236	1.973	1.973	6.602	-0.016	-0.220	-0.588	4.00	8.40	0.00
13	RLA	D	2.952	0.0755	0.0773	0.0113	1.764	1.764	6.012	0.000	0.452	0.857	0.00	0.00	0.00
14	RH	E	1.095	0.0115	0.0094	0.0037	0.543	1.750	4.310	0.000	1.107	0.592	-14.00	6.00	-7.70
15	LUA	F	4.207	0.1141	0.1213	0.0236	1.973	1.973	6.602	0.000	0.220	-0.588	0.00	6.00	0.00
16	LLA	G	2.952	0.0755	0.0773	0.0113	1.764	1.764	6.012	0.000	-0.452	0.857	0.00	0.00	0.00
17	LH	H	1.095	0.0115	0.0094	0.0037	0.543	1.750	4.310	0.000	-1.107	0.592	14.00	6.00	7.70

CARDS B.3

JOINT					LOCATION (IN) - SEG(JNT)			LOCATION (IN) - SEG(J+1)			JOINT AXIS (DEG) - SEG(JNT)			JOINT AXIS (DEG) - SEG(J+1)		
J	SYM	PLOT	JNT	PIN	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL	YAW	PITCH	ROLL
1	P	K	1	0	-1.45	0.00	-2.24	-2.39	0.00	2.25	0.00	0.00	0.00	0.00	5.00	0.00
2	W	L	2	0	-1.76	0.00	-0.83	-0.32	0.00	6.99	0.00	0.00	0.00	0.00	5.00	0.00
3	NP	M	3	0	-0.27	0.00	-7.26	-0.93	0.00	1.46	0.00	0.00	0.00	0.00	10.00	0.00
4	HP	N	4	0	1.01	0.00	-2.51	0.28	0.00	2.27	0.00	0.00	0.00	0.00	10.00	0.00
5	RH	O	1	0	-0.51	2.14	1.52	-0.32	-1.96	-7.55	0.00	0.00	0.00	0.00	-45.00	0.00
6	RK	P	6	1	-0.23	0.38	9.80	0.67	-0.58	-6.91	0.00	0.00	0.00	0.00	60.00	0.00
7	RA	Q	7	0	0.39	-0.76	9.78	1.37	-0.33	-2.76	0.00	0.00	0.00	0.00	10.00	0.00
8	LH	R	1	0	-0.51	-2.14	1.52	-0.32	1.96	-7.55	0.00	0.00	0.00	0.00	-45.00	0.00
9	LK	S	9	1	-0.23	-0.38	9.80	0.67	0.58	-6.91	0.00	90.00	0.00	0.00	60.00	0.00
10	LA	T	10	0	0.39	0.76	9.78	1.37	0.33	-2.76	0.00	0.00	0.00	0.00	10.00	0.00
11	RS	U	3	0	-0.96	6.57	-4.35	0.52	-0.52	-5.22	0.00	90.00	0.00	0.00	-4.10	0.00
12	RE	V	12	1	-0.64	-0.41	5.04	-0.53	0.23	-4.18	0.00	0.00	0.00	0.00	-70.00	0.00
13	RW	W	13	0	0.36	-0.01	5.77	0.55	0.22	-2.62	0.00	0.00	0.00	0.00	-4.10	0.00
14	LS	X	3	1	-0.96	-6.57	-4.35	0.52	0.52	-5.22	0.00	0.00	0.00	0.00	-70.00	0.00
15	LE	Y	15	0	-0.64	0.41	5.04	-0.53	-0.23	-4.18	0.00	0.00	0.00	0.00	-4.10	0.00
16	LW	Z	16	0	0.36	0.01	5.77	0.12	-0.55	-2.62	0.00	0.00	0.00	0.00	0.00	0.00

JOINT TORQUE CHARACTERISTICS

FLEXURAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. LINEAR (J=1)	(INLB. /DEG**J QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	0.000	10.000	0.000	0.700	20.000
2	W	0.000	10.000	0.000	0.700	20.000
3	NP	0.000	5.000	0.000	0.700	25.000
4	HP	0.000	5.000	0.000	0.700	25.000
5	RH	0.000	10.000	0.000	0.700	70.000
6	RK	0.000	1.800	0.000	0.700	60.000
7	RA	0.000	7.000	0.000	0.700	35.000
8	LH	0.000	10.000	0.000	0.700	70.000
9	LK	0.000	1.800	0.000	0.700	60.000
10	LA	0.000	7.000	0.000	0.700	35.000
11	RS	0.000	10.000	0.000	0.700	122.500
12	RE	0.000	1.800	0.000	0.700	70.000
13	RW	0.000	1.800	0.000	0.700	35.000
14	LS	0.000	10.000	0.000	0.700	122.500
15	LE	0.000	1.800	0.000	0.700	70.000
16	LW	0.000	1.800	0.000	0.700	35.000

TORSIONAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. LINEAR (J=1)	(INLB. /DEG**J QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	0.000	10.000	0.000	0.700	5.000
2	W	0.000	10.000	0.000	0.700	35.000
3	NP	0.000	10.000	0.000	0.700	35.000
4	HP	0.000	10.000	0.000	0.700	35.000
5	RH	0.000	0.800	0.000	0.700	40.000
6	RK	0.000	0.000	0.000	0.000	0.000
7	RA	0.000	10.000	0.000	0.700	26.000
8	LH	0.000	0.800	0.000	0.700	40.000
9	LK	0.000	0.000	0.000	0.000	0.000
10	LA	0.000	10.000	0.000	0.700	26.000
11	RS	0.000	10.000	0.000	0.700	65.000
12	RE	0.000	1.800	0.000	0.000	45.000
13	RW	0.000	10.000	0.000	0.700	65.000
14	LS	0.000	10.000	0.000	0.700	45.000
15	LE	0.000	0.000	0.000	0.000	0.000
16	LW	0.000	1.800	0.000	0.700	45.000

JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT		VISCOUS COEFFICIENT (INLB. SEC./DEG)	COULOMB FRICTION COEF. (INLB.)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC.)	MAX TORQUE FOR A LOCKED JOINT (INLB.)	MIN TORQUE FOR UNLOCKED JOINT (INLB.)	MIN. ANG. VELOCITY FOR UNLOCKED JOINT (RAD/SEC.)	IMPULSE RESTITUTION COEFFICIENT
1	P	0.100	0.00	30.00	0.00	0.00	0.00	0.00
2	W	0.100	0.00	30.00	0.00	0.00	0.00	0.00
3	NP	0.100	0.00	30.00	0.00	0.00	0.00	0.00
4	HP	0.100	0.00	30.00	0.00	0.00	0.00	0.00
5	RH	0.100	0.00	30.00	0.00	0.00	0.00	0.00
6	RK	0.100	0.00	30.00	0.00	0.00	0.00	0.00
7	RA	0.100	0.00	30.00	0.00	0.00	0.00	0.00
8	LH	0.100	0.00	30.00	0.00	0.00	0.00	0.00
9	LK	0.100	0.00	30.00	0.00	0.00	0.00	0.00
10	LA	0.100	0.00	30.00	0.00	0.00	0.00	0.00
11	RS	0.100	0.00	30.00	0.00	0.00	0.00	0.00
12	RE	0.100	0.00	30.00	0.00	0.00	0.00	0.00
13	RW	0.100	0.00	30.00	0.00	0.00	0.00	0.00
14	LS	0.100	0.00	30.00	0.00	0.00	0.00	0.00
15	LE	0.100	0.00	30.00	0.00	0.00	0.00	0.00
16	LW	0.100	0.00	30.00	0.00	0.00	0.00	0.00

SEGMENT INTEGRATION CONVERGENCE TEST INPUT

SEGMENT NO.	SYM	ANGULAR VELOCITIES (RAD/SEC.)			LINEAR VELOCITIES (IN/SEC.)			ANGULAR ACCELERATIONS (RAD/SEC.**2)			LINEAR ACCELERATIONS (IN/SEC.**2)		
		MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR
1	LT	0.010	0.010	0.0100	0.010	0.010	0.0100	0.100	0.100	0.1000	0.100	0.100	0.0100
2	CT	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
3	UT	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
4	N	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
5	H	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
6	RUL	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
7	RLL	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
8	RF	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
9	LUL	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
10	LLL	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
11	LF	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
12	RUA	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
13	RLA	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
14	RH	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
15	LUA	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
16	LLA	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000
17	LH	0.010	0.010	0.0100	0.000	0.000	0.0000	0.100	0.100	0.1000	0.000	0.000	0.0000

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